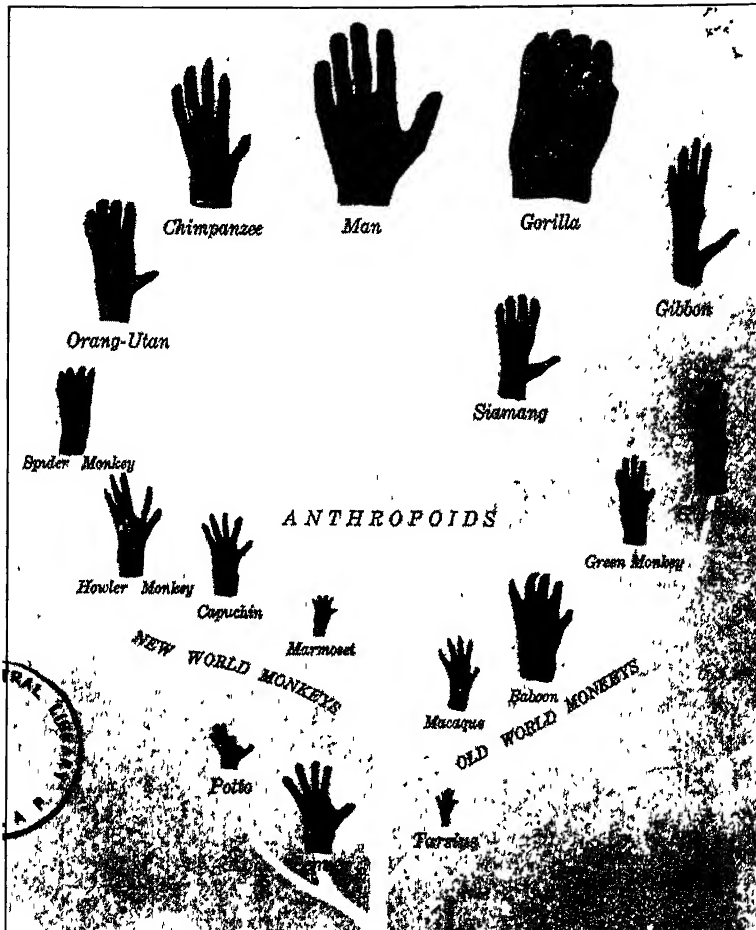

frontispiece

EVOLUTION OF THE HAND

(After W. K Gregory)

The Story of
EVOLUTION

Facts and Theories on the Development of Life

By
BENJAMIN C. GRUENBERG

1830 1930
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To

SIDONIE MATSNER

WHO HAS TAUGHT ME MANY THINGS
OF WHICH SCHOOLS HAVE AS YET
NO INKLING, IN GRATITUDE AND
DEVOTION

PREFACE

Are you an evolutionist? Are you an anti-evolutionist? It really does not matter. What matters is the quality of thinking you do to justify your position.

We take our beliefs and our labels very seriously; and we should, for after all they are ours, they represent our very selves. And yet, not too seriously; for we may be worrying unnecessarily about beliefs and labels that are not truly our own. We may have picked them up inadvertently. They may have been stuck into our pockets during a fit of abstraction. They may have been sold to us when we were off guard. All sorts of very nice people have this belief, or that one. It's quite all right for you to have your belief, whatever it is. But how did you come by it?

It is not the purpose of this book to prove or disprove "evolution." For one thing, the word evolution stands for too many different kinds of ideas that have nothing to do with one another, or, for that matter, with the main idea of this book. For another thing, some ideas cannot be "proved" in any strict sense. We can prove the presence or absence of silver alloy in a golden crown, but we cannot prove that Archimedes ran naked through the streets of Syracuse shouting Eureka, or that he ever took a bath. We know that a young man in love will go to great lengths, but we cannot prove that Leander swam the Hellespont. We can find evidence that the plants and animals now inhabiting the earth are different from the inhabitants of a former age; but we can not prove that the later "evolved" from the earlier.

Because the word evolution stands for so many different ideas it has been necessary to explain the sense in which the word is used in various connections. We are concerned chiefly with organic evolution, *the process whereby the stream*

of life continues down the ages to manifest itself through new individuals that differ from one another and that form constantly changing groups or species.

Are the various species of plants and animals self-contained realities, or are they mere abstractions of the human mind? Have the species of living things existed unchanged from their several beginnings, or have they become, in the course of time, transformed into different species? The facts bearing upon these and other common-sense questions, the facts that have to be explained and reconciled, are presented objectively and concretely, in the hope that readers of diverging views may find them significant and helpful. The need for a general theory and the more plausible special theories are then discussed. Finally, the practical importance of organic evolution is pointed out. There is no attempt to establish any general doctrine of evolution as applying to stars and planets, to atoms and molecules, to musical instruments and social institutions.

I wish to express my sincere thanks to the many friends who have helped me with criticisms and suggestions, and especially to Dr. R. A. Budington of Oberlin College; Dr. Otis W. Caldwell of Teachers College, Columbia University; Dr. Winterton C. Curtis of the University of Missouri; and Dr. Caswell Grave of Washington University. I am under obligation also to the numerous scientists and publishers, and to the American Museum of Natural History, for the use of illustrations, which are individually acknowledged in the book.

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INTRODUCTION

THE normal human being, shortly after he begins to walk and talk, is brought by his walking into contact with new objects and new happenings which arouse his curiosity. And he uses his talking to ask, " What is that? " For a time this potential intellect is satisfied with the names of objects. In the course of time, unless he is repressed or diverted, he will ask the more searching question, " How come? " In regard to the vast array of plants and animals that will come to his attention, two classes of answers have been offered, yea three. To dismiss the last one first, as unworthy of serious consideration, we are reminded that for some people a satisfactory answer to the question as to the origin of the many living things is to say that they have always been as they are now. The other answers are, First, things were specially created. There are two different variants of this answer: (a) Each species or kind of living thing was created by itself and has remained from the beginning as we find it today; (b) The world was created in such a way that the different living beings automatically came out of the mechanism. This latter is substantially the explanation of creation offered by Saint Augustine. Second, plants and animals evolved from simpler to more complex forms in accordance with the uniform action of natural forces, such as are constantly at work in the world.

The conception of a continuous process of change, in the course of which the whole world and all of its inhabitants come to be progressively different, appears very early in human thought. Long before Aristotle, *becoming* was clearly differentiated by philosophers from *being*. The fact that aspects of nature are constantly changing is perhaps accepted by casual observers as a purely short-time phenomenon. The

daily cycle and the seasonal cycle may limit for many people the span of attention and the range of imagination. From earliest times, however, close observers have noted much more. The actual composition of the living world is changing although it is at this stage impossible to go farther back than the memory of a life-time. Well on into the Christian era the thoughtful observers and the meditative minds were "evolutionists." That is, those who thought at all took it for granted that plants and animals changed not only in the course of each individual's development, but also in the course of time from one type to another. *The existing population,* it was assumed, *is descended from its ancestors with constant change.*

From the time of St. Augustine in the Fifth Century both the theologians and the lay scholars accepted as a matter of course the descent of living forms of the present from more primitive ancestors as part of the historical view that everything which has come to pass is part of the unrolling of the scroll of the universe. This general theory of evolution was colored at one time by Greek speculation about the nature of the world and of matter. At another time it was colored by theological speculations of the church fathers, yet it was a part of the intellectual equipment of western civilization through many centuries.

There is no essential difference between the evolution of modern biologists and the evolution of Saint Augustine, except perhaps in the former's search for mechanisms and in the latter's assumption of an ultimate act of creation. The scientist does not pretend to know what the beginnings of life were. For his purposes, the study begins with things as found. However far our speculations may lead us, he considers the ultimate questions of origins, purpose and destinies as outside his special province.

A middle-aged person who is told for the first time that the world is round would find it difficult to assimilate the idea to his previous experience and thinking. It is not stupidity that makes one ask how the inhabitants of the an-

tipodes get along upside-down. Those already accustomed to certain notions regarding the nature and origin of the earth and its inhabitants would find it equally difficult to consider a radically new statement, such as the evolutionary hypothesis, and to make it fit into past experiences and thinking. Quite aside from the several accounts found in Genesis, the folklore and common assumptions of many peoples take for granted the existence of plant and animal forms as distinct species, in the sense that each derives from its own ancestors independently of others. Linnæus himself, the Swedish naturalist who in the Eighteenth Century laid the foundation for the scientific classification of living things, and who devised the binomial system for naming species, considered the different forms as absolutely independent units. He declared that the number of species in the world is as many as the number of different forms created in the beginning.

The doctrine of special creation, that is, the creation of " a pair " of each kind of plant and animal as the ancestors of all succeeding life forms, was not a part of orthodox teaching. This assumption, with the corollary that each line of descendants remains specifically true to form and distinct from all other species, was, in fact, an open and explicit contradiction of the teachings of Saint Augustine, who in turn had apparently been influenced by the teachings of Aristotle. It was only in the Sixteenth Century, under the influence of the Spanish theologian Suarez, that any systematic attempt was made by the church authorities to formulate a doctrine regarding the origin of the living world in harmony with the stories presented in Genesis. This contributed a great deal to the destructive and confusing hostility between science and theology for generations to come. Professor Osborn writes, " if the orthodoxy of Augustine had remained the teachings of the Catholic Church, the final establishment of [the doctrine of] evolution would have come far earlier than it did, certainly during the Eighteenth Century instead of the Nineteenth Century, and the bitter

controversy over this truth of nature would never have arisen." The assimilation of the notion of special creation as a definite act at a definite point in time was furthered by the graphic and dramatic embodiment of this conception in Milton's "Paradise Lost." To this day, most people who have absorbed something of the verbal and literary culture of recent centuries are unable to distinguish the Miltonian poetry from the Mosaic symbolism, and either of these from elementary facts of geography and astronomy.

Most people in our times have been more or less thoroughly indoctrinated by their parents and by their religious teachers with the idea of special creation. The doctrine of evolution has been very commonly considered as conflicting with "religious" teaching. There is, however, no necessary conflict between such a doctrine and religion. This we may infer from the fact that men and women who are sincerely devoted adherents of many diverse denominations and sects have accepted whole-heartedly the evolutionary point of view. Many professional religious leaders are fond of declaring that religion is not in conflict with "true science," but must reject the "false science" of evolution. One is tempted to say that evolution is derived from the study of the actual world and cannot therefore be in conflict with "true religion," but must reject the "false religion" which refuses to face this world of actuality. But obviously this does not lead us anywhere.

We already know that every living being comes from parents of the same "kind," and produces offspring of the same kind. The transmutation of species, however, implies that one kind of being produces not according to its kind: that violates our common experience. It asks us to think that the offspring of given parents are the same and yet not the same: that violates common sense.

Difficulties of a different kind have been introduced by those who espoused, with an enthusiasm approaching religious fervor, the new ideas about the descent of species from different ancestors. These promoted the idea of "evolu-

tion" as an article of faith — an article of faith in conflict with prevailing beliefs and assumptions, and yet necessary for salvation or for some other benefit. Such enthusiasts, concerned more with a spread of *sound doctrines* than with the promotion of *clearer thinking*, have often been quite as dogmatic as those who resist conversion. They have been as much disposed as any dogmatists to appeal to authorities and to "arguments" rather than to the facts themselves. The results have been an overemphasis upon the value of opinions and a confusion as to the meaning of evolution as understood by scientists.

Further misconceptions arise from the difficulty of maintaining always an objective and impersonal attitude. Even professional scientists confronted with a public asking to be educated (or at least shown) have been disposed to diverge from the main issue to discuss theories and speculations which the layman confuses with the major principles. Or they have quarrelled among themselves as to technical matters that do not affect the main question, regardless of how they are settled. To this day, people who ought to know better assist the uninformed in confusing the idea *that* the world is constantly changing with Darwin's effort to explain *how* new species arise. To this day, professional scientists wrangle among themselves as to the practical application to be made of certain purely theoretical principles. In this way they impress the uninformed not with the unanimity among the scientists about the fact of the evolution of life, but with the disagreements among scientists — about something or other that has to do with evolution. In discussing principles of heredity, principles of morphology, principles of embryology, or in attempting to interpret a newly discovered fossil, the play of personal opinion, the wide range of speculation, and the necessarily large amount of disagreement as to many details bring, to the general public, nothing at all of the meaning of the discussions, but only an intimation that the evolutionists are quarrelling or that there is a "crisis" in evolutionary thought.

From the point of view of promoting knowledge, the subject matter of a study should be presented as objectively as possible. There should be a statement of the facts marshalled to bring out their relationship, and there should be a statement of the generalizations derived from these facts, of the theoretical interpretations of the facts, and of their practical significance. It is almost impossible today to discuss evolution in this manner. Objective and inductive study is so new a method in the intellectual life of the race that most people still get their views of the world as finished pictures transmitted by authority. The diffusion of specialized knowledge among the general public is so recent a development that most men and women approach the subject of evolution from a background of doctrine with which evolution is supposed to be in conflict. With every desire to avoid argument, we find ourselves contrasting the plausibility of an evolutionary interpretation with that of special creation. As attention is fixed more and more upon the facts, however, the evolutionary interpretation becomes progressively more satisfying to the thoughtful person, notwithstanding the increasing difficulty of "explaining" evolution by any simple formula.

This book attempts to separate the presentation of evolution as a historical process from the various theories designed to account for the origin of species in a rational manner. The purpose is not to convert skeptics and doubters but to inform all and sundry (1) of the meaning of the doctrine from the point of view of the scientist; (2) of the facts upon which it rests; (3) of the more important attempts to explain the processes discussed; and (4) of the practical implications of the point of view involved.

THE FACTS OF EVOLUTION

Chapter I

The Common Sense of The Evolution Question

THERE has been so much controversy about "evolution," that the person who wants to make up his mind for himself finds it very difficult to get the necessary information without prejudice. One who starts his inquiry with an open mind finds it difficult even to obtain definitions that make clear what the discussion is all about. Indeed, it is fair to ask whether it is ever possible for anyone who knows a great deal about a subject of dispute to state the *facts* without prejudice. Even where we intend to be perfectly fair, each of us must be influenced to a greater or less degree by his own views in *selecting* the facts. It is nevertheless possible to recognize some of the difficulties and problems in the mind of one's opponent or in the mind of the doubter, and to try to give at least a clear statement of one's views and of his reasons.

Conclusions versus Facts

Whenever there is heated or prolonged controversy about any subject, most of the debate and argument concern themselves with conclusions. Each partizan does indeed muster an array of "facts" to support his conclusions, or to discredit the conclusions of his opponent. But the difficulties lie deeper. When we are not ourselves deeply stirred, we can observe that those taking part in a controversy or dispute usually differ as to the meanings which they attach to important terms. Or they differ as to the values which they place upon various objectives, actions, or relations. Or they

differ as to the assumptions which they make regarding the nature of the world, of life, of the ways in which things come about, and so on.

As an example of one type of thinking, take the case of one who looks up the origin of the word evolution in the dictionary, and finds that it comes from the Latin and means an unfolding, a turning or rolling outward from within. With this definition as a basis, one can construct a great deal of nonsense and show that "evolution" implies many things that we know are not so. We know that a butterfly cannot roll out of a worm, or a frog unfold into a snake! Thus it is easy to "disprove" evolution.

Or one can find a statement by an acknowledged or an avowed "evolutionist" regarding protective tariff, or capital punishment, or any other subject, and from this we can show that evolution must be wrong because it leads to practical conduct which we and our neighbors disapprove.

Or we might say, as many do, that any attempt to "explain" our world in a thoroughly rational way leaves out "the necessity for a God." Now, since evolution is a rationalistic way of looking at things, we can dismiss it in advance as unsound.

Manifestly a person who is really open-minded cannot be satisfied with conclusions obtained in any of these ways. These are but different ways of using our previous conclusions to block the way to new ideas. We ought to ask rather, — What does evolution mean to those who consider themselves evolutionists? What are the facts that make the idea acceptable to so many people who are not obviously stupid, or insane, or perverse? What does it imply in a practical way in the management of our daily affairs?

A Historical Process

It may be well to stop for a moment to ask just what evolution means, at least to the scientist.

First and fundamentally, evolution is the name we give

to the total historical process, the changes through which all things pass, and especially, to the changes through which the forms of plants and animals have passed in the course of time. As a historical process evolution is considered by scientists as a *fact*, in the same sense as we speak of the "growth of the British Empire" as a fact, or the "industrial revolution," or the "replacement of the horse by the motor car." It is recognized, of course, that these "facts" are of a different order from the multitude of simple experiences and judgments that make up our every-day contacts with the world — I feel hot, it rained yesterday, the diamond is harder than glass, the clock struck ten.

We "Know" More Than Facts

Every adult whom you have known for many years was at one time a child. Some of the other adults of your acquaintance have intimated in one way or another that they too were once children. Although you have not known all of your acquaintances during their childhood years, to say nothing of all the other adults in the world, it is not difficult for you to feel sure that *every* adult was once a child. Indeed, it would be difficult for you to believe the opposite.

From our common experience with human beings we get certain facts and certain theories that we constantly take for granted in all of our thinking. We have the *facts* about the origin of certain particular individuals from parents, and about the development of certain individuals from babyhood to adulthood. We expand or extend these familiar facts to *all human beings now living* (whom we could not possibly have known ourselves). We extend them to all human beings who have lived in the past (with perhaps a few exceptions).

Then we have similar facts about other living things, plants as well as animals. We make a parallel extension from our experience and observations to other plants and animals

that we have never seen, and to plants and animals of former times. Some of us go even farther and extend our general ideas to the plants and animals of tomorrow and of all future time.

These examples will illustrate a common quality of the human mind. From *particular* observations or facts (which must necessarily be limited in number) we build up *general* ideas about whole classes of things. Then we make use of these generalizations *as if* they were facts. In most cases we are on safe ground, as when we say night and day alternate, or rain comes from clouds. But sometimes our generalizations go too far, as, for example, in the case concerning many plants, in which it would be impossible for us to tell exactly what an "individual" is, or to trace it to its "parents," or even to its "babyhood."

The Particular and the General

The scientist realizes the danger of extending his generalizations too far. He makes a special effort to be sure of the facts; and he tries his material out on other people. That is, he compares notes with others, to be sure that the facts look the same to most people. But beyond that he tries to check up his generalizations in as many ways as possible, to see whether they will hold under all conditions. And finally he tries to keep always in mind the difference between the known facts and the generalizations which he uses, so as to be prepared on short notice to recognize an exception to his inclusive statements about whole classes of things.

In the ordinary course of becoming acquainted with plants and animals as well as other material, we all use in a practical way the same methods as the scientist. We get facts, we generalize from them, and then we use the general ideas as though they were true. If you like your fountain pen, you say "Jones pens are good." If a grocery clerk short-changed you, you are suspicious of grocery clerks. If you get sick after eating caviar for the first time, you say

caviar is indigestible. The soundness of your ideas has no connection with the *certainty* that you feel about them. The soundness depends upon the number and range of *facts* upon which they rest. Everybody must have noticed that some people feel sure about many things that are not so at all. On the other hand, many people hesitate to speak positively even when they are well supported in their ideas. Our feelings, apparently, cannot be relied upon to make sure that what we firmly believe is really true.

It is common sense to feel sure about many things that we have not actually observed directly. It is a little better than common sense to make sure *how reliable* our generalizations are.

Certainty Beyond Facts

The facts that we know about living plants and animals, and the facts that we have been able to gather about dead ones, lead to the generalization that the living forms of a given period are the descendants of the living forms of an earlier period. Probably no sane adult questions this. A second generalization is that in the course of time the descendants of plants and animals have become so modified as to constitute "species" distinguishable from the ancestral types. This is really the core of the evolution controversy. Instead of calling this process "evolution" we call it development, or, as concerns organic forms, continuity of life with modification, or descent with modification. When we use the term evolution in this sense it is without prejudice as to the *origin* of the process, as to the *course* which the process has run or will run, as to whither it will lead, or as to the *causes* or forces which bring about the changes observed.

Now it must be freely admitted that when doubters ask for "proof" of this evolution, it is quite impossible to furnish it, since the historical past is always a matter of inference or conjecture, with more or less of probability to qualify it. Did George Washington ever live, or, having

lived, did he "cross the Delaware"? The Delaware still flows on, and we have hundreds of legends and monuments and main streets that presuppose the previous existence and activities of "Washington." But quite as much may be said of many a Greek god or hero. There is Mount Olympus, there are statues, temples, and other monuments. Who of us accepts as a *fact,* because of these, the historical reality of Zeus?

What We Can Know of the Past

When we speak of the past, the past that extends back beyond our own remembrance, it is difficult to make sure of facts. It is common sense to believe that things existed before we were born, and that things happened pretty much then as they do now. Still, reasonable as this belief is, it is not direct knowledge. There are some people who get themselves into a frame of mind that doubts whether anything ever did or does now exist except *in their own minds.* But if we are not satisfied with our own conceit, we are obliged to take a great deal on faith — that is, we have to believe what we are told about the past. Even so simple an assertion as "I was born" involves a distinct succession of deductions with an unquestioning faith in one's postulates. Such an assertion cannot rest on direct knowledge. You may know that you exist; you cannot know so directly that you were born, although the inference is reasonable and the conclusion highly probable.

In order to build up an acceptable picture of past events we are obliged to depend upon more or less reliable records of various sorts. We are constantly doing just this with the utmost confidence in the soundness of our method. On the other hand, the very people who seem to have the greatest doubts regarding the evolutionary mode of restating what has been found out about the past accept most uncritically as historical truth all sorts of unsupported myths and unverifiable legends.

We do not have to believe everything that we are told about the past. We can choose to believe only what seems to us reasonable, or we can frankly choose to believe only those stories that please us. That is indeed the way most people read history. They either believe everything they read and ask for no evidence, or they believe only those things that fit in with their preconceptions, whether political, national, religious, or whatever they may be.

The history of the earth cannot be read out of books in the way that history of human events of the past can, since the changes that have taken place in the waters and continents and glaciers and volcanoes occurred (as we infer) long before there were any human beings to report the events. The footprint which Robinson Crusoe saw in the sand was a fact. That a human being had trodden the beach before him was an inference. Similarly, the "facts" which the scientist observes are present to our senses; but we have to consider them as evidence of what occurred in the past, and draw our conclusions accordingly. These facts, about which there can never be any dispute, we find in the very structure and composition of the earth itself, in the fossils, in the beds of salt and sandstone and various other minerals. People differ only in the inferences and conclusions they draw from the facts.

Assumptions

If it is possible to consider the historical past of the earth and of its inhabitants in a common-sense way, it must be by being clear in our own minds as to what we assume about the world of matter and life. For facts do not speak for themselves. They have to be assorted, pieced together, related to other facts. In short, they have to be *interpreted*. But such interpretation depends upon previous experience, and especially upon what we assume to be the workings of the world.

The first of these assumptions which the scientist makes

is the principle of *continuity,* or the constancy of the universe — what is now, ever has been and shall remain.

Nothing New Under the Sun

Millions of gallons of water pass over Niagara Falls every week. Yet the Falls look about the same as they did several years ago when you first saw them. They remain the same year after year, and, for all we know, century after century. The oceans and lakes and the everlasting hills give us a hint of eternity. The stars that blink silently in the sky have seen hundreds of generations come and go, but their positions, their risings and their settings remain fixed and steadfast.

The materials of the earth remain the same. Man may pile rock upon rock to build him tombs or temples: but he creates nothing new. He merely rearranges what his hands have found. While some of the combinations that human ingenuity has set up may amuse us or startle us, we know that they are only *new combinations* of what has already existed. Every house, for example, is but a variation on a very ancient theme. Shooting off a sixteen-inch shell is but a variation of the game which David played with Goliath.

It is common sense to recognize that, in spite of constant change, today is the daughter of yesterday. In human experience events do not jump out at us from a vacuum. If the world is always changing, it is still always the world. The very changes show a certain constancy — day and night; season after season; generation, maturity and death. If it is common sense to recognize the facts of change, it is also common sense to recognize the enduring things of life and of the universe, the uniformities and constancies by which alone we can guide ourselves in the midst of change. It is these enduring uniformities that science seeks to discover. And that, too, is a part of the study of evolution, for here we seek to answer not only the question "What changes

have taken place?" but the further question "How come changes?"

This brings us to the second assumption, the principle of causation.

Cause and Effect

One aspect of the idea of evolution, namely, that "one thing leads to another," has been thought by people for thousands of years. At some time or other every person, every child who thinks at all, wonders about the connection between the past and the present. Even little children get the notion that things which are happening now must somehow have gotten started in what has happened before. We may not hold to this idea permanently, or consistently; but we all get it. For example, a boy finds a horseshoe and takes it home, in accordance with the superstitions of his neighborhood, *hoping* that it will bring him "good luck." Yet many a child of six years has sense enough to ask, "How can finding a horseshoe have anything to do with what is going to happen to you?"

Common experience suggests that everything that happens is related to something that happened before. Everything that happens makes something else happen which otherwise would not have happened. This idea is sometimes spoken of as the principle of *causation,* and it is as old as the records of human thought. Now frankly, we cannot say exactly *how* one event makes another one take place. We all have noticed, however, that certain kinds of events always do follow others without fail. A hole in the rain barrel will "cause" the water to leak out. A break in the rope of the painter's scaffold will "cause" the scaffold to drop. A collision between a trolley car and an automobile will "cause" damage to one or the other, or both. A spark applied to gunpowder will start something. A drouth will somehow interfere with the growth of the crop, and so on.

While the principle of causation is part of our daily

efforts at understanding, it is not of itself so simple as to "explain" events and experiences automatically. Most of our common thinking about cause and effect is carried on in mechanical terms — push and pull, levers and wheels, hammer and tongs, the workings of our common implements and tools. The cause-and-effect relationship of many of the processes going on around us are not as easily restated from the observed facts. A person of ordinary intelligence can understand the working of a pair of shears, or the connection between winding a watch and the movement of the hands. One has to have an exceptional amount of intelligence as well as of special information to understand what connection there is between turning the knob on the radio receiver and "tuning in" for a given broadcasting station. Strictly speaking, nobody understands what connection there is between the properties of common salt and the properties of the two elements, sodium and chlorine, of which it consists. We nevertheless assume that here as in the more familiar experience the principle of causation applies. Nothing happens without a cause and, generally speaking, nothing happens without causing something else to happen.

Now, any child who gets this notion into his head, and who is also observant enough to see that things around him are different from what they were a few weeks or months ago, will soon come to another common-sense idea. And that is, since everything that happens causes other things to happen, and so on indefinitely, the passing of time will witness a more or less gradual change in all things — faster in some, slower in others, but still a constant and progressive change.

Assumptions Cannot be Proved

In our practical affairs and in our reasoning, most of us accept without question these two principles — the principle of causation and the principle of uniformity. We could hardly carry on our daily affairs without accepting them.

But most people also accept them without realizing that they are assumptions which, from the very nature of things, *cannot be proved.* If we find a satisfactory cause for an event 999,999 times, we cannot "prove" that things will work the same way the millionth time.

The principle of uniformity is also a pure assumption, in the sense that it can never be proved. After a million trials we may feel confident, for example, that a pound of lead will take up less space than a pound of marble the next time we have anything to do with lead and marble; but we cannot "prove" that this has always been the case, or that it would be true on Mars, or next year.

Of course we do not have to make these assumptions if we do not choose to. We do, however, have to be clear about them, as assumptions, when we are discussing evolution (or any other subject for that matter) else we are apt to become confused.

From these assumptions it follows that any inference we may draw as to past events must be in terms of known materials and forces and relations. The methods of science when applied to the materials of the earth, organic and inorganic, lead to inferences regarding ancient shore lines and glaciers, regarding the antiquity of various structures and formations, regarding the anatomy and even activities of plants and animals that no human being ever saw. The results constitute the descriptive material of evolution.

Things Are Not What They Used to Be

If you go away from home for a year, you will find on your return that things are not what they used to be. Even without any special disaster or epidemic, ten to a dozen people out of every thousand have died since you left. Many babies were born in your absence. Some of the houses have burned down, and new ones have been built. The fields and orchards may look the same as they did, but millions of seeds have sprouted; millions of plants have grown to maturity, pro-

duced their seeds in turn, and have died. The blossoms on the trees are not the ones you saw. Those have long since disappeared, and these were not even "in the bud" when you went away. Millions of flies and mosquitoes flew up from manure piles or water puddles, lived their little day and passed on.

With the changing seasons, nay, with the coming of day and night, all things about us change: men and women and children, all living things and things not living, the things of nature and the work of man's hands. If you stay in one place, and do about the same work day after day, you may not notice that things are constantly changing. Yet whenever you see a person after a separation of some time, you are struck by the changes that have taken place. When you take leave of your companions, and hope to meet them again at some future time, you know in your heart,

> Ne'er the self-same men shall meet;
> The years will make us other men.

It is common sense to recognize that things are constantly changing. We may not know just how it is that night gives way to day, but we know that it does. We may not understand exactly how it is that the seasons follow in their regular succession, but we know that they do. We may not know just how a person grows up and becomes day by day a different person, although always recognizable as the same, and how he finally declines and dies; but we cannot live long in this world without discovering that such changes do actually take place.

Evolution an Ancient Conception

The earliest philosophers were impressed with growth, change, decay. Aside from any belief we may have as to what it is that brings about growth and change, there ought to be general agreement that "all things flow" — unless we declare that all is illusion.

It is but a short step in our thinking to ask whether the world as a whole is changing. Has the world always been the same as it is now, except for the ebb and flow of the tides, for example, or except for some other reversing change? Have the plants and animals that live upon the earth, and in the air and in the water, always been the same in kind? Are changes in living things only such as come with the changing seasons, or have there been in the past forms of life different from those we see today? In the absence of means for directly observing the *facts* on the earth before we were born, one guess is perhaps as good as another. It is common sense, however, to make use of whatever existing facts we can gather, as well as of any other knowledge we can get as to how things do happen — that is, as to the uniformities in change, or the *laws* that appear to us to be enduring.

Organic Evolution

Things change. The materials of the universe endure. Changes take place according to certain uniformities: nothing happens without cause. Changes produce effects. The workings of the world are the same in all parts; they are the same always. It is common sense to be guided by facts and by certain kinds of inferences from facts. It is common sense to assume that the workings of the world which we can observe today are the same in kind as those of past time.

The main propositions regarding the evolution of life upon the earth, then, are:

(1) The animals and plants of today are descendants of animals and plants that lived before them, and these in turn were the offspring of other living things;

(2) In the course of time the descendants of some forms or types came to be different from their ancestors.

There is continuity, but there is also change, or, briefly, life presents a history of descent with modifications.

While nobody has lived long enough to have observed

these things happen (since the statements apply to the events of millions of years), it can be shown that both propositions are supported by *facts.* These propositions are not self-evident. They raise questions in the minds of every thoughtful person. For example, what is there to show that the living kinds or species of plants and animals have not always been the same as those we find today? How can we tell the " relationship " between living things of today and those of former times? If all life comes from life, where and how did life originate? How did changes or departures from ancestral types come about? If this process has been going on, what does it lead to? These are all common-sense questions, and there are many others.

Obviously such questions cannot be answered by argument. Some of them at least can be answered satisfactorily only by facts — facts in regard to which there can be no argument. If it is true that all living things have descended from remote ancestors, with more or less modification in the course of time, we ought to be able to find direct and unmistakable evidence, even if we never find out how the changes are brought about, how the series started, or what it is leading to.

As to the questions of the origin of life and the ultimate destiny of man or life in general, science has nothing to say. The individual scientist, in common with other human beings, may have his hopes and fears and beliefs. In common with other more or less intellectual beings he may speculate all he likes. His method as scientist, however, does not permit him to deal with these questions. The reason for this is that he knows no way of bringing the material under direct observation, or of subjecting it to experimental conditions. This is not to say that we have reached the limit of the knowable. On the contrary, the problem of the " origin of life " is being constantly attacked by experimental methods and it is unsafe to predict what facts may be found. The distinction merely means that the scientist as such is not primarily concerned with ultimate questions of whence or

whither. These are philosophical questions, and he has to lay them aside during his working hours.

It is helpful to distinguish, at any rate, the philosophical idea that all things change, from a scientific attempt to record facts and to work out from these facts an understanding of just how it is that changes are brought about. In this second scientific sense, " evolution " is a generalization from a vast multitude of facts, a working hypothesis by means of which the scientist attempts to make an intellectual reconstruction of the world, or to " explain " the relations of various parts to one another.

We shall try to keep clear the *facts* that record the historical process of change in the world and its inhabitants, and to discuss separately the various attempts to explain how it all may have happened, or the *theories* of evolution. Finally, we shall consider the importance of knowing the facts, and the importance of finding reasonable theories that fit the facts.

Chapter 2

The Make-Up and the Workings of the Earth

THE study of evolution carries within itself the special difficulties of any historical inquiry. There is the need of finding significant documents or evidences, and of ascertaining their dates or time sequences. Then there is the need of interpreting the evidence into an account that is not only consistent within itself but also in harmony with what we know of the workings of things in general. There are many facts regarding past events which may be authentic enough but which the historian considers irrelevant for his purpose. In the same way the student of evolution, who must of necessity begin all of his studies with facts of variation, has accumulated a tremendous body of such factual material only to find that much of it is irrelevant for his purpose.

The historian often finds spurious evidence. There are forged documents, there are hoaxes, there are deliberate falsifications. There are records that seem to say one thing but really mean something else. There seems also to have been at work a process that we have come in recent years to call propaganda. Such material is significant for the historian, but obviously it needs a great deal of critical checking and testing. In the same way the student of evolution finds facts that seem superficially to carry one set of implications but that on more critical examination may mean something totally different. The general form of the whale, for example, which is enough like a fish to make the ordinary observer class these mammals with fishes, has been interpreted on the one hand as showing special creation for life under special

conditions, and on the other hand as showing the selective action of the environment in bringing about adaptation; and still other interpretations may prove to be sounder. The remarkable resemblances in general appearance sometimes found between insects of different families, even of different orders, is an impressive fact which undoubtedly has some bearing on the question of evolution, but the analysis of this fact into its fundamental physiological sources has discredited the doctrine of "mimicry" as a support of the general doctrine of organic evolution.

Many Sources of Error

In the study of fossils it has been necessary to guard against casual lumps of stone or clay that resemble superficially some structure produced by an animal. Nobody today believes that fossils represent mere freaks of nature, or the playful production of mineral imitations of organic structures by a creative intelligence, yet there have been found clods of earth that were only clods of earth, in spite of such resemblances. When the explorers of the Gobi Desert brought back petrified Dinosaur eggs, it was proper not only for skeptics but for sympathetic scientists to ask, "How do you know they are eggs and not rounded stones?"

The historian must be on his guard against falsifications of the records by accidental or by intentional dislocations. The finding in an emperor's tomb of a sword showing workmanship and ornamentation characteristic of a foreign people is a significant fact for the historian; but he does not have to elaborate it into showing the versatility of the emperor or of his artisans. In the same way the student of evolution must guard against drawing faulty conclusions from dislocated materials. Holes dug for water or for minerals or even for scientific purposes have displaced the original inclusions and so have misled later students. Materials transported by man or washed out of place by inundations have complicated

the interpretation of the facts presented by the crust of the earth. The first Neanderthal remains were found by some workmen digging in a cave and were thrown out with other debris. This made it impossible for the first scientist who reached the material to know very definitely about the exact location of the fossils in the rocks. A matter of a few feet would be of importance in determining the relative age of the bones. It was only because so much material was subsequently found in its original location that anthropologists have been able to build up a consistent interpretation of these remains. When Du Bois found the fragments of his Pithecanthropus erectus, the different pieces were several yards apart. This made it impossible to tell whether they were parts of the same individual. A similar doubt has been raised regarding the fragments of the Piltdown skull found in England in 1911.

As the historian is compelled at times to struggle with a hoax, the scientist has also been confronted with materials deliberately planned for the purpose of misleading or challenging the student. There is a classic story of a professor of entomology upon whom the students played a practical joke by gluing together the wings, legs, antennae, and abdomen of totally different insects into a " specimen " which they brought to the professor for identification. The professor glanced at the monstrosity and concluded at once that it was a " humbug." Generally speaking the serious student does not suspect a hoax and takes the material as it comes to him in good faith. The incongruities eventually reveal themselves, however, and by dint of prolonged study these initial difficulties are overcome.

The Origin of the Earth

The scientist does not pretend to know directly how the earth began its career as a separate body in space, among other planets and moons and stars. There are many facts that have a bearing upon the probable history of the earth as

a planet, but the conclusion is always in the nature of an inference more or less probable; or if you like, it must always be a "guess." The available facts are those that the astronomer can find in the sky — the behavior of suns, that is, stars, and nebulas. There are also facts to be observed upon the earth and within the earth. From these facts various theories have been developed as to the probable course of events that led to the present constitution of the earth. It may be said at once that no theory is altogether satisfactory since none takes account of all the known facts; and perhaps each theory is at some point inconsistent with known facts. It should be added, however, that this in no way discredits these theories since they have served a very useful purpose in guiding scientists in the collection of facts, in making observations, and in checking or criticizing one another's observations.

Guesses at the Past

In trying to understand what happened during the early history of the earth, we have assumed that the happenings in any case were the same as those which occur today *under similar circumstances.* For example, What does water do to different kinds of materials? How rapidly does water carry sand away? How rapidly does sand settle at the mouth of a river or in a lake? How rapidly can rivers carry away dissolved materials from the soil? Rain falling upon bare soil or sand washes the particles down and carries them along in its course (Fig. 1). Water soaking into the soil dissolves certain substances, leaving others undissolved. The water gathering into brooks and rivers finds its way at last into the ocean. Here the heat of the sun brings about evaporation of the water but leaves behind the dissolved solids, whereas the suspended or floating particles settle to the bottom. The scientist assumes that water has always behaved in these ways with relation to sand or soil, with relation to soluble substances, with relation to heat.

It is a comparatively simple matter to determine how many thousands of tons of silt and sand are carried into the Gulf of Mexico by the Mississippi River every year. From such facts it has been calculated that the entire Mississippi River basin would lose a quantity of soil equal to a layer one foot deep in the course of 6000 years. As an actual fact soil is being removed much more rapidly in some regions,

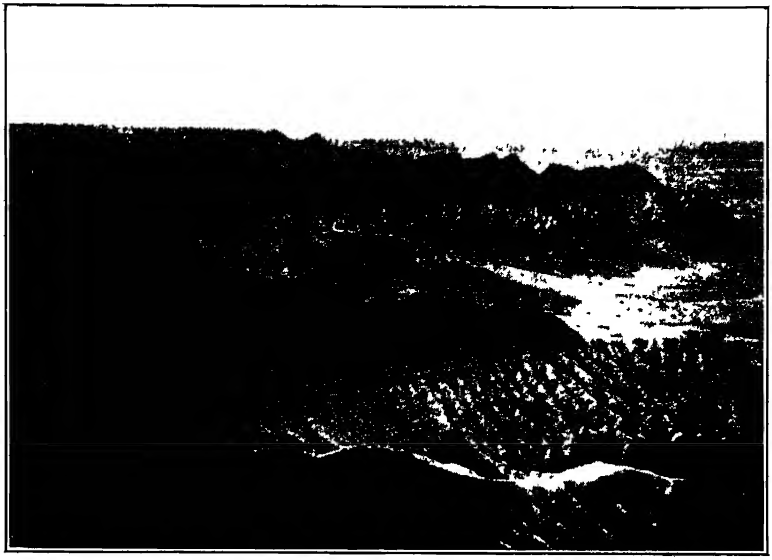


FIG. 1. MASSIVE EROSION IN MONGOLIA

The bad lands at Urtyn Obo show the effects produced during the ages by the action of rain and flowing water upon the sands and rocks. From photograph by the Gobi Desert Expedition of the American Museum of Natural History.

but much less rapidly in others. The Ganges River is washing parts of India away at the rate of an average one-foot layer in about 850 years. Soil is being thus steadily removed throughout the whole world.

By accumulating in detail numberless facts of observation and measurement and experimentation, scientists have attempted to answer such questions with respect to many kinds of soil or sand and with respect to the different substances that water dissolves out of the soil. With the answers

to these questions, which are assumed to hold for past times as well as for the present, we try to rebuild the past. This is illustrated by what we know about the weathering of rocks.

Weathering

Many of the stone buildings in our cities and towns show the effect of changes in weather and temperature. Certain of the softer red sandstones scale off very quickly. A hard crystalline rock, such as granite or marble, endures much longer than sandstone or a porous rock. When water soaks into the tiny cracks or pores of a rock and then freezes, as on cold nights, the expansion of the ice makes pieces of the rock split off.

Waves beating upon the rocks on the shore will pound the hardest granite to pieces. In its descent as rain, water absorbs carbon dioxid from the air and comes to act as a weak acid, which is a solvent for many minerals. The wind carrying moisture or particles of sand also tends to grind down rock. The effect of this process is sometimes seen in the appearance of the window glass of a lighthouse which is etched by the wind-driven particles of sand in a severe offshore storm. If we assume that similar processes have been going on in the past, we not only account for facts that are readily observed, but we have also a means of *measuring* how rapidly important changes have taken place in the past. Recognizing the impossibility of getting direct observations, and our need of depending upon inference from observed facts, we may still speak with some confidence as to what has happened.

Measuring Processes of the Past

Any one of us, looking at the Niagara Falls today, can see the reasonableness of the idea that the edge of the rocks, over which the water plunges, was farther down the valley ten years ago or fifty years ago than it is today. Of course

the reasonableness of the idea does not make it a fact. There are, however, actual records kept since 1843, and from these we know that the Falls have been cutting the gorge back an average of 104 inches a year. Is it not reasonable to suppose that many years before human records were made as to the precise location of the Falls, at some very remote date, the edge of the rock was still farther down the valley? We have exactly the same confidence in the statement that the Falls were farther north a thousand years ago than they are today as we have in the statement that the Falls existed before the discovery of America.

Let us assume then that this process of water tumbling over the rock has been going on in the past. Let us assume further that this tumbling of water which today wears away rock has in the past also worn away rock. We may then ask, How long has it taken the discharge of water from Lake Erie into Lake Ontario to wear back the gulley from its northern end to the present location of the Falls? With such assumptions, the performance which man has been able to observe as a fact is extended backward in time. The result of the calculation is that it must have taken between thirty and forty thousand years for the gorge to have been cut back the distance from Lake Ontario — about twenty miles. And this calculation we accept not as an accurate statement of fact, but as an *approximation,* since we realize that we have no way of knowing whether the volume of water has been the same year after year, and since we do know that the resistance of the rock and soil has *not* been exactly the same throughout the whole length of the distance.

Sedimentation

At a relatively early stage in the formation of the earth, we conceive the temperature to have become sufficiently lowered to condense most of the water vapor into fluid, and to leave masses of the continents exposed above the ocean. The action of the weather broke down this original crust and

particles were carried by the streams to the sea or other bodies of water. The settling of the sand resulted in the formation of deep layers of such material, and under great pressure these layers became cemented into sandstone (Fig. 2). An examination of chalk deposits shows the rock to consist of a sediment of microscopic shells like those formed today by animals similar to the ameba. A handful of slime taken from

FIG. 2. SEDIMENTATION

Vast areas have been dug up by water and wind, and by the hand of man, exposing layers of the earth's crust that had been slowly deposited in past ages, grain upon grain. From photograph by the Gobi Desert Expedition of the American Museum of Natural History.

the bottom of the sea in some places would show millions of such microscopic shells. Limestone, which has the same chemical composition as chalk and marble, contains bits of shells of larger animals as well as skeletons of different types, and the geologist assumes that these structures are the remains of animals that lived many years ago. Coal has also been considered a kind of sedimentary rock bearing the remains of plants which grew in swamps ages ago. In other rocks we

find shells resembling those of microscopic one-celled plants living in lakes and oceans today. The formation of sandstone, chalk, limestone, diatomaceous earth, and coal, by the sedimentation of the materials of which they consist, must have been a very slow process, judging by the rate at which sedimentation today takes place in seas and lakes, and by the multitude of living things represented by even a very thin layer of one of these rocks.

Layers of Crust

In the gorge of Niagara, in the Grand Canyon of the Colorado, in most other deep valleys we can see layers or strata of soil and rock on opposite sides of the cut. On a smaller scale we can observe the same appearance in an artificial cut made for a railroad, or even for a ditch. In the latter cases we can see at once that the layers on one side of the cut correspond to layers on the other side because continuous layers have been interrupted by the digging. The various layers differ in color, in the coarseness or fineness of the particles, in the character of the materials. These characteristics enable us to identify the corresponding layers on opposite sides. We may also see that there is the same order or arrangement of the distinguishable layers. Having concluded that the gorge or valley has been cut through the rocks and soil by the action of moving water, as the railroad cut has been produced by the action of moving picks and shovels, we assume that the layers on one side were at one time continuous with the corresponding layers on the other side, as is the case in the artificial cut.

These strata happen to be practically horizontal in many parts of the earth, and the character of the material is such that, although nobody ever saw them being formed, we feel safe in assuming that they were produced by the settling of solids out of water and the subsequent compression of the settled sand or mud into the hard layers. They are, at any rate, just what we should expect them to be *if* they had been produced in this manner.

It is in this way that scientists build upon observed facts inferences as to past happenings. It is by the careful measurement of present-day happenings that they build up inferences as to the rate at which events of various kinds took place in the past. From such studies and calculations various estimates have been made regarding the age of the earth. These estimates of the earth's age, made by various methods, do not, it is true, agree very closely with one another, since it is necessary to speak in terms of millions of years.

The Age of the Earth

A consideration of salt in the sea has served to furnish one series of estimates. From the careful analyses of waters that empty into the ocean we may form an estimate of how long it took for the salt in the ocean to accumulate. Unfortunately, estimates of the total amount of water in the ocean must leave a rather broad margin of error.

Similarly, we may make estimates of the earth's age from the thicknesses of various layers of deposits of sandstone or other sedimentation, from the rate at which exposed rocks are worn away by weathering and rain, from the rates at which glaciers move, and so on. In every case there is necessarily a considerable element of inaccuracy. The greatest objection to each of these methods, and the probable reason for their lack of agreement, is that we cannot be sure that the processes measured went forward at a uniform rate. Salts may have been carried to the sea much more rapidly, or much more slowly, in past ages. Sedimentation in the ocean might have been faster or slower, depending perhaps upon the density of the waters due to the amount of salt in solution, or upon varying depths.

The most reliable methods for estimating the age of the earth have been developed in very recent times from a study of the curious fact that the element uranium steadily throws off certain particles or emanations and becomes converted into lead. These discoveries have been made only since the discovery of radium by Pierre and Marie Curie in the

nineties of the last century. The transformation of the heavy element uranium is known to proceed at a very definite rate. Moreover, this rate appears to be uninfluenced by temperature or by any of the other conditions to which the uranium can be exposed in the laboratory. It is possible for the skillful worker in the laboratory to determine the proportions of uranium and lead in certain minerals, and from this proportion to calculate the age of the minerals, assuming that all of the lead present is derived from uranium. Thus, pitchblende obtained from the Black Hills was estimated to be 1,500 million years old. A mineral from very old rocks in Norway appears to be 900 million years old. Studies of the atomic weight of lead enable the chemist to tell whether a given sample was lead to begin with, so to say, or derived from the breaking down of uranium. Determination of the ratio of uranium and lead in minerals of corresponding periods obtained from different parts of the world show remarkably close agreements.

We must remember that in dealing with such enormous figures, where a few million years more or less are of relatively slight consequence, there is necessarily a considerable range of disagreement among the various calculations. On the other hand, there is a tendency toward substantial agreement regarding the age of the earth as the various methods of calculation become more refined.

Relative Ages of Different Formations

After all this speculation regarding the age of the earth, it must be admitted that for our purpose it does not really matter how old the earth may be. It is important for us only (1) that we be clear as to the facts and assumptions upon which the age of the earth is calculated; and (2) that we be clear as to the reliability of our judgments regarding the *relative ages* of the various layers.

Wherever the layers or strata are perfectly horizontal it is readily agreed that they resulted from sedimentation of

material under water. We must further agree that the lower layers were deposited before the upper layers, that each layer is older than those above it and younger than those underneath.

When we compare series of strata in one part of the world, or even of the same country, with series in another region, it becomes often impossible to establish any kind of correspondence. Layers of coal in Pennsylvania, for example, we may believe to be older than the rocks found above them and more recent than the underlying rocks; but how can we tell whether they belong to the same period as coal layers in Indiana or in England?

Another difficulty in interpreting the relative age of the earth's layers is met when the strata are not perfectly horizontal. Again and again we find layers tilted at every possible angle. Now the geologists find good reasons for assuming that these tilted layers were originally horizontal and were forced into their existing positions by a slow or rapid upthrust from below. The crust of the earth has become wrinkled, chains of mountains having been pushed out. Or sudden eruptions, like volcanic outbursts, have pushed the crust up. The continuity of strata can often be traced on opposite sides of such outbreaks. In other cases the record has been marred by the action of the weather and of waters. In some cases masses have been completely turned over, so that the layers lie in an order opposite to that in which they were originally put down. These and other irregularities have made it impossible in the past for the geologist to read the rocks as directly and clearly as we should like, especially when comparing structures widely separated in space, or on different continents.

Fossils

A great aid to reconciling the scattered facts was found in the observation made by an English surveyor in the Nineteenth Century. William Smith, who traveled extensively

in connection with his work, kept a record of the fossils which he found in the different kinds of rocks. He became so familiar with their distribution in various parts of the country that he could always tell what kinds would be found in a given layer of rock, what kinds would be found above and what kinds would be found below. In other words, he had discovered a certain uniformity in the distribution of fossils with respect to *the relative ages of the rocks.* While he did not know much about the plants and animals which these fossils most closely resembled, he did know what he had seen: the types of animals and plants to which these fossils corresponded resembled existing plants more and more as the layers from which they were taken were nearer to the surface, or more recent.

Fossils had been known for centuries, but their significance is a comparatively modern discovery. The ancients either looked upon them as "freaks of nature," or took them to be what they are, namely, the relics of dead plants and animals, without understanding the importance of their existence. Those who wondered about them at all usually invented fantastic "explanations." For example, they were supposed to be evidences of nature's plasticity. A rock might take on one shape as well as another, and some happen to take on these queer shapes suggesting monstrous animals or parts of animals. Or they were supposed to be abortive attempts of nature to produce animals. A parallel idea was that the creator had made numerous experiments before he decided upon the species of animals and plants with which he was going to people the earth, and the fossils were the discarded models. Again, the fossils were put in the earth to confuse the geologist and to humble him with the futility of trying to understand the inscrutable ways of providence. Or they were put in either by God to test men's faith, or by Satan to tempt and mislead us.

At the end of the Fifteenth Century, Leonardo da Vinci, the artist and thinker, gave a very simple explanation of fossils. They are the remains of animals left in the sand or mud.

The difficulty of explaining the presence of sea shells and remains of crabs and other marine forms among the rocks of a mountain he met with the simple assumption that these rocks were at one time covered by water. That in fact is our understanding today.

There is abundant evidence that land levels are gradually being raised, even out of the sea. There is abundant evidence that areas now covered with water were at one time high and dry. Fossils are found in sedimentary rocks for common-sense reasons. Rocks that have been molten must have had destroyed in them every vestige of living remains they may have contained. Rocks that have been formed by the grinding away of older rocks must have had destroyed in them the remains of living bodies they may have contained. It is only the intact strata of former sea bottoms or lake bottoms that are likely to contain any considerable amount of plant or animal remains. That is what we find to be the fact.

Fossils as Guides to the Age of Rocks

From William Smith's observations geologists obtained a clue to the relative age of rocks, when comparing formations in different regions with one another. Rocks containing large proportions of Trilobites (Fig. 3), for example, were older than rocks containing remains of fishes. Coal strata, containing remains of giant club mosses and tree ferns, were older than strata containing fossils of the giant reptiles, and so on. This idea makes possible the useful comparison of series of strata in different parts of the world, and has found its practical application in the search for coal, oil, and other minerals. It cannot, however, be applied without reservation to all regions as a means of determining the approximate age of a given formation. It is conceivable, for example, that although the *order* in which different types of fossils appeared is the same in all parts of the world, the absolute time at which a given series started was not the same. Thus, coal beds in England, in Indiana and in Ger-

many may contain similar fossils, the rocks below the coal beds may contain similar fossils in all three regions, and the rocks above the coal beds may also contain similar fossils. Yet all that we can say is that these various types of fossils appeared in the same *order* in the three countries. We cannot be sure that the corresponding layers were formed at approximately the same time. They may have been separated from each other by millions of years.

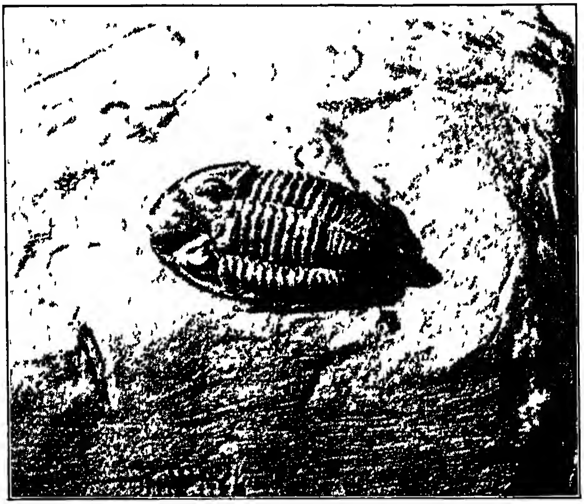


FIG. 3. A TRILOBITE

Fossil remains of an animal related to the horse-shoe crab, from Keokuk limestone Photograph, courtesy of the American Museum of Natural History

The order in which different types of fossils appear in the layers of rock is, however, of great importance in considering the question of evolution. The first significant set of facts is this: in a series of fossils taken from successive layers of rocks, the oldest or deepest correspond, in their resemblances, to simpler plants and animals, while the more recent, or those nearer the surface, correspond to more complex plants and animals. Again, where we find sufficient resemblances between the fossil forms and existing species

to recognize, we find consistently, as William Smith had pointed out, that the more recent fossils resemble the living forms most, and that the oldest fossils resemble them least. Moreover, we find in many cases a fairly continuous series of forms connecting the oldest with the most recent.[1] This fact is called the geologic succession.

Modification of Earth's Inhabitants

In general terms then we find the observed facts regarding the remains of plants and animals that lived in former ages quite consistent with the idea that there has been in the course of ages a gradual modification in the living inhabitants of the earth. There is nothing, however, to show us that the species living in one period were connected with those of another period by actual descent. The succession may have been, for all we know, like the replacement of candles by oil lamps and of oil lamps by electric lights. Indeed, the first scientist to make a systematic study of fossils for the purpose of determining the *kinds* of animals they represented was quite convinced that there was no genetic connection. Georges Cuvier, the founder of comparative anatomy, had so thoroughly familiarized himself with the details of structure of many backboned animals, especially of their skeletons, that he claimed to be able to recognize a bird or a mammal by one of its bones. In the course of the extensive diggings in Paris in 1800, the workmen uncovered large fossil bones, the original sources of which they could not know. Many guesses were made — they were the remains of giants, perhaps, or monsters of a former time, but nothing that people could recognize. These fossils were brought to Cuvier, who at once recognized that they were elephant bones! But there were no elephants in the neigh-

[1] A century ago it was necessary for the student of paleontology to depend upon fossil types to give him the key to the chronological sequence of the rock deposits. The accumulation of more and more facts has made it possible to reverse this method and to determine the fossil sequence by a study of the rock formations in which they were found.

borhood of Paris. Nor had there been any so far back as anybody knew. Moreover, these bones belonged to elephants that were different from any living species of elephant. From the study of these fossils and of others, Cuvier came to the conclusion that there had at various times existed upon the earth species of animals that were no longer living. Now, he had always assumed that each species of plant or animal was a fixed reality and could not be changed into another species. He therefore went a step further and concluded that there had been a succession of cataclysms in the history of the earth, in the course of each of which all life had been destroyed. After each cataclysm, Cuvier supposed, a new set of living things was created. While the fossils of one period resembled those of another, as some fossils resembled living species, there was no connection between the fossils of one period and those of another. The oil lamps on which we model our electric lamps were the predecessors but not the ancestors of our present day lamps. In the same way, the extinct animals of former ages, according to Cuvier, were the predecessors of living forms, not their ancestors.

It must be recognized that the known facts were at least in part favorable to this view. First of all there are earthquakes, there are volcanic eruptions, there are floods. These movements in nature are sometimes very destructive. Then there were the fossils. These were so distributed as to suggest that water had replaced land and land water. They were also distinct enough in each great formation to be looked upon as a separate set of creations. Finally there was the ancient tradition and common sense that considered each species as something apart from other living things.

Cuvier was the foremost authority on the anatomy of backboned animals. He was also thoroughly convinced of the fixity of species. According to his interpretation the evidence of the rocks tells us that (1) species of past ages are now extinct, and that (2) there appeared upon the earth, from time to time, new species that had not existed in the past. *There has been a succession of species.* So much

Photograph from Culver Service

GEORGES CUVIER

FRANCE 1769–1832

we can accept as fact. This sound principle thus established by Cuvier did not show him that transformation of species had taken place. Yet it must be clear that unless a succession of species were established, we could not today confidently uphold the doctrine of evolution. Here Cuvier, an opponent of the idea of evolution of living forms, helped to lay the foundation for the idea — as we shall see later, he did the same in another important corner.

Incompleteness of the Geological Record

In order to make the fossils show that, in addition to a succession of species, there was also continuity of life, it would be necessary to find a complete, continuous series of species from the ancient forms to those now living. Such continuity of fossil forms does not exist, except in scattered instances. Before considering these we should first ask ourselves whether it is reasonable to expect such complete series. Take the life of man upon earth within historic times. In how many families would it be possible to point to the material remains of half a dozen generations of direct ancestors? Of the millions of people who have died within a century, how many have left any material remains whatever, to say nothing of recognizable skeletons?

The conditions under which fossil remains are to be expected are rather restricted, so that for many forms that may have existed upon the earth we can expect no representative relics at all. There are the many species of microscopic plants and animals which have no hard parts that could be preserved. If they existed in past ages we can see today only such evidence of their activities as the decayed remains of larger plants and animals, since we now know that the decay was due to the feeding and fermenting processes of microörganisms. At any rate we know that today decay is due only to such processes. Then there are the animals whose fossil remains are buried under the bed of the sea, quite inaccessible, and likely to remain so at least for

centuries. Then there are the larger plants and animals that lived on the land, or in the air, and whose bodies were either devoured by other living things, or decayed and scattered. For we must remember that as a rule fossils were formed only where dead bodies were buried in mud or sand.

Now there are a few exceptional finds that point to extinct forms of a kind that we should not ordinarily expect among the fossils. In Siberia, buried in ice and preserved for countless centuries, there have been found several specimens of an extinct relative of the elephant, the mammoth, with flesh and hide and hairs and all. There they were, about as large as life, saved from decay by the low temperature, and, by being buried in the ice, saved from destruction by other animals and by the weather. Indeed, so well preserved was the flesh that the dogs ate it with relish. A tar pool in California yielded the nearly intact remains of elephants, camels, horses, wolves and saber-tooth tigers, all animals that have not been living on this continent for millions of years.[2]

The conditions under which fossils are formed, the ease with which dead remains of living things are devoured, decayed and scattered, and the operation of destructive forces and upheavals, all make for incompleteness in the geological record. Perhaps we can realize this if we consider that of the thousands upon thousands of wild bisons or "buffalo" that roamed our prairies within the memory of middle-aged men and women, there are few skeletons ever found. What should we expect to find of the other land animals and birds that undoubtedly occupied this land when Columbus arrived? Where can we find relics of the passenger pigeon that occurred a generation ago in vast swarms? Or of the antelope? Or of the prairie dog? Our record must necessarily be incomplete, and only a small fraction of it has in any case been reached by the explorers. Such as it is, however, it points not only to a succession of diverging species, but also to a suc-

[2] The ancestors of the modern horse that lived on this continent in ancient times died out completely. The modern horse was brought here by Europeans after Columbus, see p. 39.

cession from more general to more special forms, and to a real continuity of life from generation to generation, throughout the ages.

Evidence of Progressive Change

If each new " creation " were unrelated to the life of the preceding geological age or ages, such resemblances as are found between fossils of different periods would be purely chance or random resemblances. As has already been stated (page 30), however, there is a constant increase in the resemblance to existing forms as we examine the fossils of later and later periods. Moreover, a careful examination of the fossils shows that the older forms are more " primitive," or less specialized in their structure. For example, the earliest fossils found in North America, in the Huronian formation, under layers of rock miles in thickness, represent simple marine forms, one-celled animals and worms. These animals were too soft to leave any record, but the protozoa formed minute " shells " and the worms formed burrows or tubes of sand, which remain after millions of years. In the next important layers are found representatives of all the principal branches of animal life except backboned animals. The most prominent form is the three-lobed " crab " or *Trilobite*, which shows affinities to worms on the one hand and to the king crab on the other.

Later deposits show remains of land plants for the first time. Corals and molluscs resembling the nautilus increase in numbers, and the period is characterized by curious fish-like animals with armored heads, the *Ostracods* (Fig. 4). These animals show traits that link them to the king crab in some respects, to the sea-squirts in other respects, and to the jawless hagfish of recent times in still other respects.

The first backboned animals to appear are the more primitive fishes and sharks which were very abundant in the period that produced the rocks underlying the coal measures. Of the other four classes of backboned animals living today,

amphibians appeared before reptiles, reptiles appeared before birds, birds appeared before mammals. These facts do not show that one class gave rise to the next "higher" class in this order. They do show that at successive periods there appeared upon the earth more and more highly specialized types of animals.

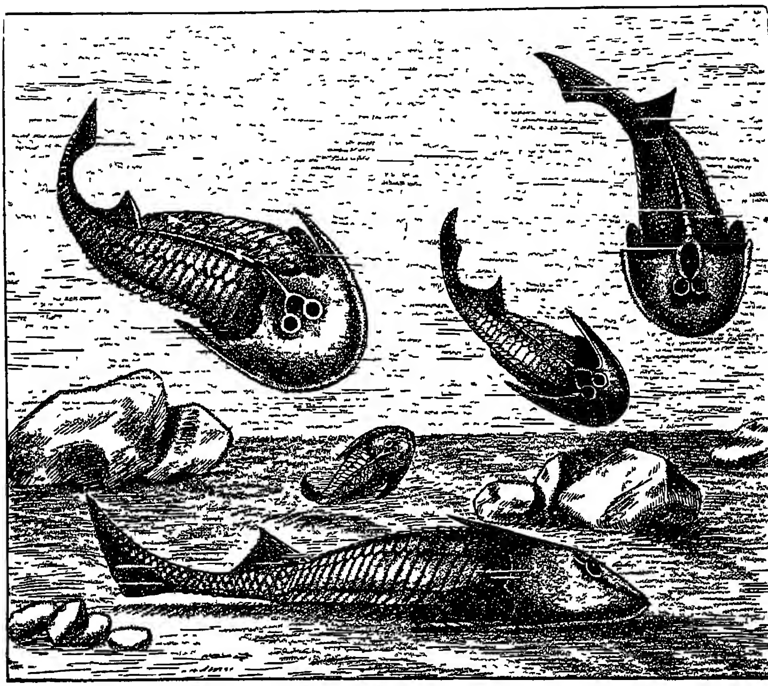


FIG 4. OSTRACODERMS

Small armored fishes from the lower Devonian of Europe. Restored from fossil remains After Koken.

The appearance of new forms of plant life at successive levels also followed a progression from those that we consider lower to those that we class as higher. Vegetation seems to have been at its rankest during the period in which the material for our coal beds was growing (Fig. 5). The conditions under which these plants grew can be compared to some of the present-day tropical swamps. True

FIG. 5. RESTORATION OF CARBONIFEROUS VEGETATION

The characteristic plants of the Coal Age resemble most closely the living families containing ferns, club-mosses and horse-tails, and many of them grew to enormous dimensions, compared to the corresponding groups of the present time.

seed-plants are found for the first time only in more recent deposits.

The fact that lower types of plants and animals are recognized in the oldest layers, and progressively higher types in more recent layers, is quite in harmony with Cuvier's view that after each supposed cataclysm a completely new flora and a completely new fauna had been created. It shows perhaps a progressive " improvement " in the living inhabitants of the earth, but it does not show evolution in the sense in which the term is today used by scientists. It is necessary to find evidence of *genetic* continuity or relationship by descent from age to age.

Was there Continuity of Life?

We have seen that the fossil record is incomplete, and that, from the nature of the case, it must remain incomplete, no matter how thoroughly the fossil hunters explore every accessible cubic foot of the earth's crust. The shells and skeletons of animals that lie buried in the slime at the bottom of lakes and seas come in the course of time to be " fossils," but only after that portion of the bottom has been raised above the water level and consolidated into rock. Another layer of sediment is formed after long lapse of time only after the surface is again submerged or flooded over, and the new covered bottom is in turn again raised aloft by the slow movements of the ocean floor or of continental masses. There must therefore be a break between the life forms of one layer and those of the next. The very conditions that brought about the formation of separate layers meant not only inconceivably long periods of time, but radically changed physical conditions, involving different kinds of plants and animals. We should expect, at best, that plants and animals forced by the changing conditions to shift to a more congenial region would leave their remains in areas remote from those containing the fossils of their ancestors, rather than in the immediately succeeding strata.

An analogy from recent social history may make this point clear. With the rapid improvement in automobiles during the first quarter of the present century there were produced many models which continued in production but a short time. Many cars were used a comparatively short time and replaced by their owners with supposedly better models. There were thousands and thousands of cars that were discarded while still usable. These gradually found their way to less prosperous parts of the community and many of them ended their existence in regions far removed from the homes of their first owners. If we wanted to assemble a series of cars to show the progress of the art in the hands of some of our first families, we could not get the needed specimens in the back yards or outhouses of the respective estates. We should have to hunt in remote rural and mountain districts, in out-of-the-way places where alone the decrepit cast-offs would be tolerated, and eventually in dumps and scrap heaps far from the main traveled roads. This would mean a zigzagging exploration, not only in space, but among different social layers of our country. It is in pretty much the same way that we must find representative specimens for any continuous series of the ancestors of living plants or animals.

With every geological or climatic change the fauna and flora of a given region changed. This does not necessarily mean that all existing life forms were exterminated. It is more likely that they merely migrated. In parts of New England today are colonies of thriving Italians, but no signs of Indians. This does not mean either that all Indians have been exterminated, or that the Italians are descended from the Indians who formerly occupied the same regions. The horses that ran wild over the prairies of the middle west during a part of the last century were not the direct descendants of the animals whose fossils have been found in Kansas and Nebraska. The descendants of those fossilized forms had long ago become extinct, and the roaming horses were descendants of immigrants from Europe within historic times.

The mere succession of forms in a given region may tell us nothing at all about the descent of the later inhabitants from the earlier ones. In some cases we can be certain that the successors were *not* the descendants of the previous occupants.

Examples of Continuity

In Slavonia there are some lakes that have been left behind by receding waters and that have been drying up slowly for millions of years. Certain fresh-water snails have been for countless generations living and dying in these lakes;

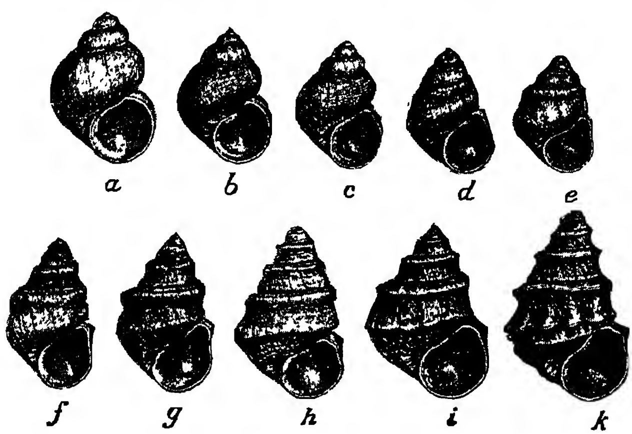


FIG. 6 VARIETIES OF PALUDINA

The fresh-water snails represented by the series of shells show enough differences between any two of them to be considered as distinct species Certainly the two extremes, *a* and *k*, would not be considered of the same species if the intermediate forms were unknown After Neumayr

and millions of the shells have dropped to the bottom, sunk into the mud, and become part of the underlying rock formation. By cutting down into these underlying rocks we can obtain shells dating back through the ages in a continuous series. If we compare the oldest shells with those of living snails we can see very marked differences (Fig. 6). If, however, we follow the shells down through the rocks — that

is to say, back through the ages — we find an uninterrupted series in which those lying nearest each other are indistinguishable, and yet the whole showing a steady transition from one extreme to the other (Fig. 7). Under these circumstances one can hardly question the genetic continuity of the

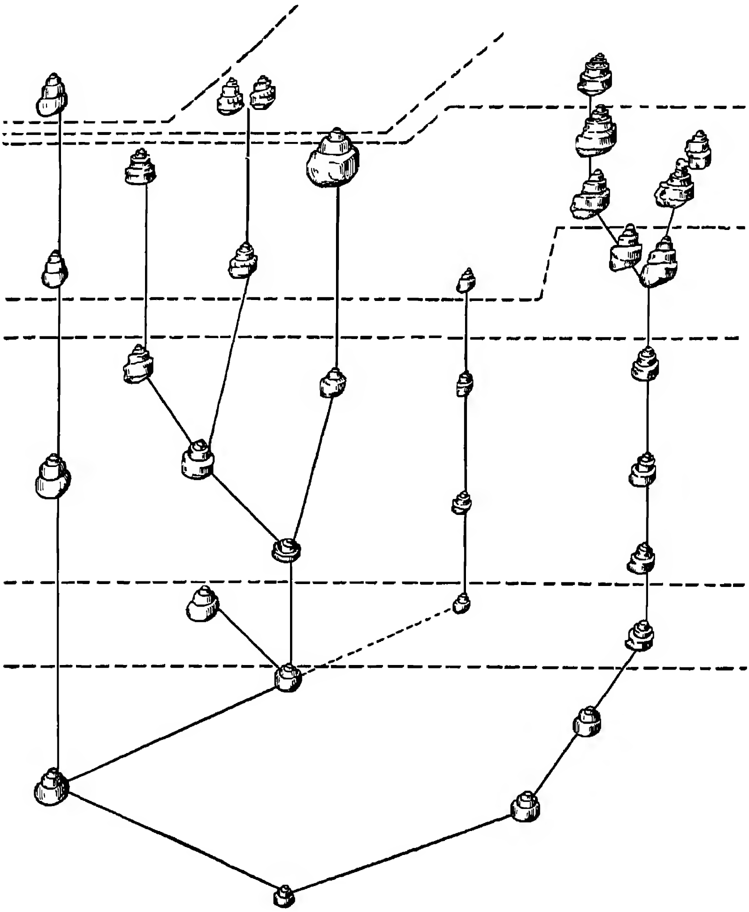


FIG. 7. DIVERGENCE OF TYPE WITH DESCENT

A study of fossil snails shows a continuity of transition from the oldest (the lowest in the diagram) to the most recent (the top row) The right end in the top row corresponds to *k* in Figure 6, the bottom form is represented by *a* in Figure 6. The study shows also divergence or branching out at successive periods After Neumayr.

group. One must conclude that the modern Paludina is descended from forms represented by the fossils, and that through the ages there has been modification along with the continuity of life, even though we may not be able to guess what brought the changes about.

Another remarkable series of snails has been worked up from Wurttemberg. Here there is not only a progressive change from the ancient type to the modern, but repeated divergence resulting in several distinct types that even an untrained eye can readily separate. There are evidences here, in other words, of an ancient ancestor with several distinct types of descendant. Similar series of sea urchins have been worked out from the chalks of England.

Evolution of Mammals

More interesting to most of us are the recent additions to our knowledge of ancient life which link up familiar animals like the horse, the elephant, and the camel with their respective ancestors.

The family to which the horse belongs (the Equidæ) is represented by fossils of the Eocene period, of little hoofed animals having five toes, and not at all resembling the modern horse in outward appearance, the *Eohippus*. Fossils found in Europe and North America supply a remarkably complete series connecting these animals with the modern horse (Fig. 8). There is a progressive reduction in the number of toes while the middle toe becomes larger. There is a lengthening of the legs. There is a lengthening of the neck and of the head. There are progressive changes in the teeth. And there is a progressive increase in body size.

Out of materials assembled from Egypt, North America, India and Europe, a fossil series showing the ancestral history of the elephant has been built up (Fig. 9). The fossils from the Eocene of northern Egypt represent an animal about three feet tall resembling the modern tapir. Fossils from the Oligocene period, found in India as well as in Egypt,

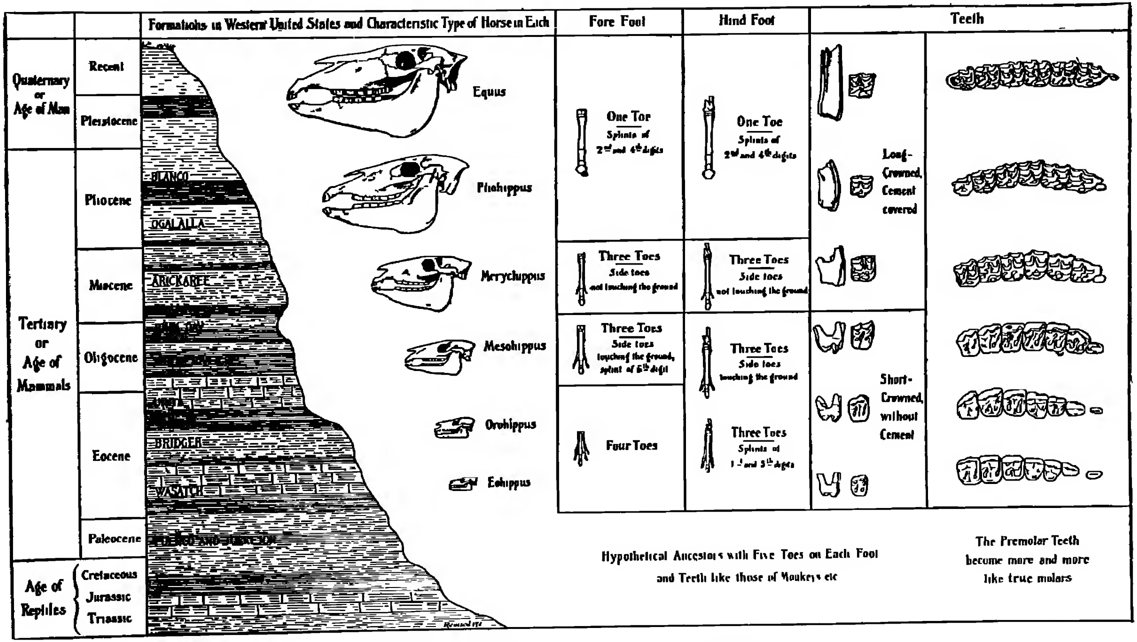


FIG. 8. EVOLUTION OF THE HORSE

Fossils of successive periods show marked and consistent differences in size, in shape of skull, in the bones of the feet, and in the character of the teeth. After Matthews Courtesy American Museum of Natural History

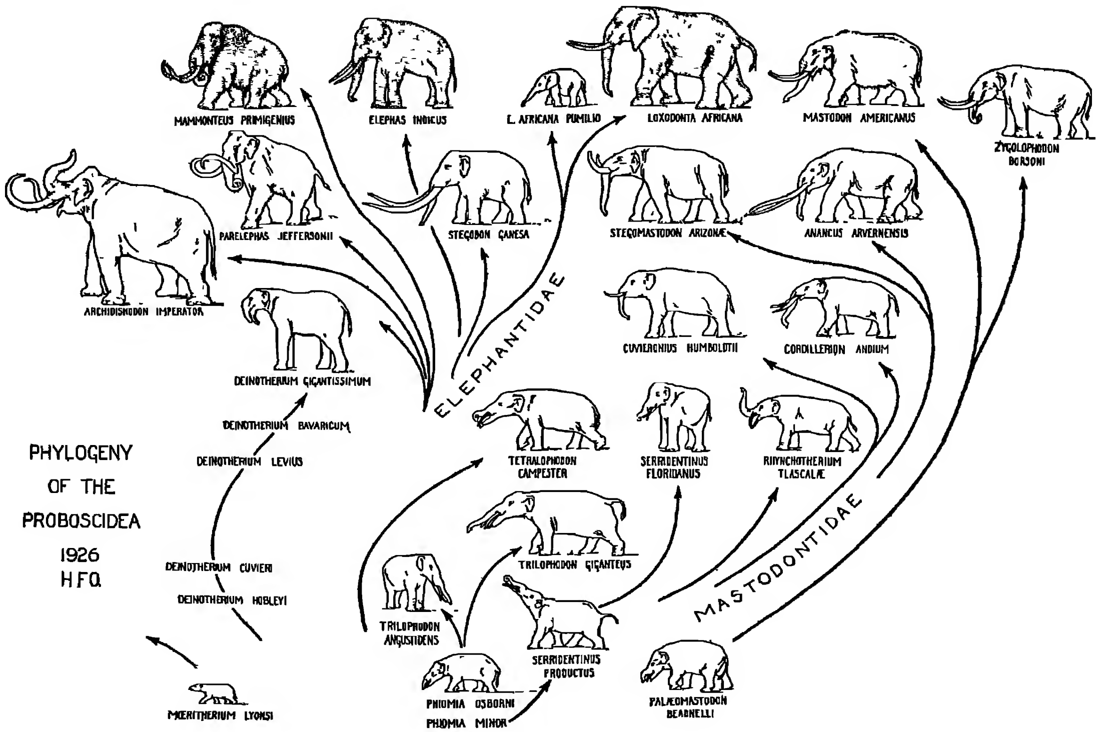
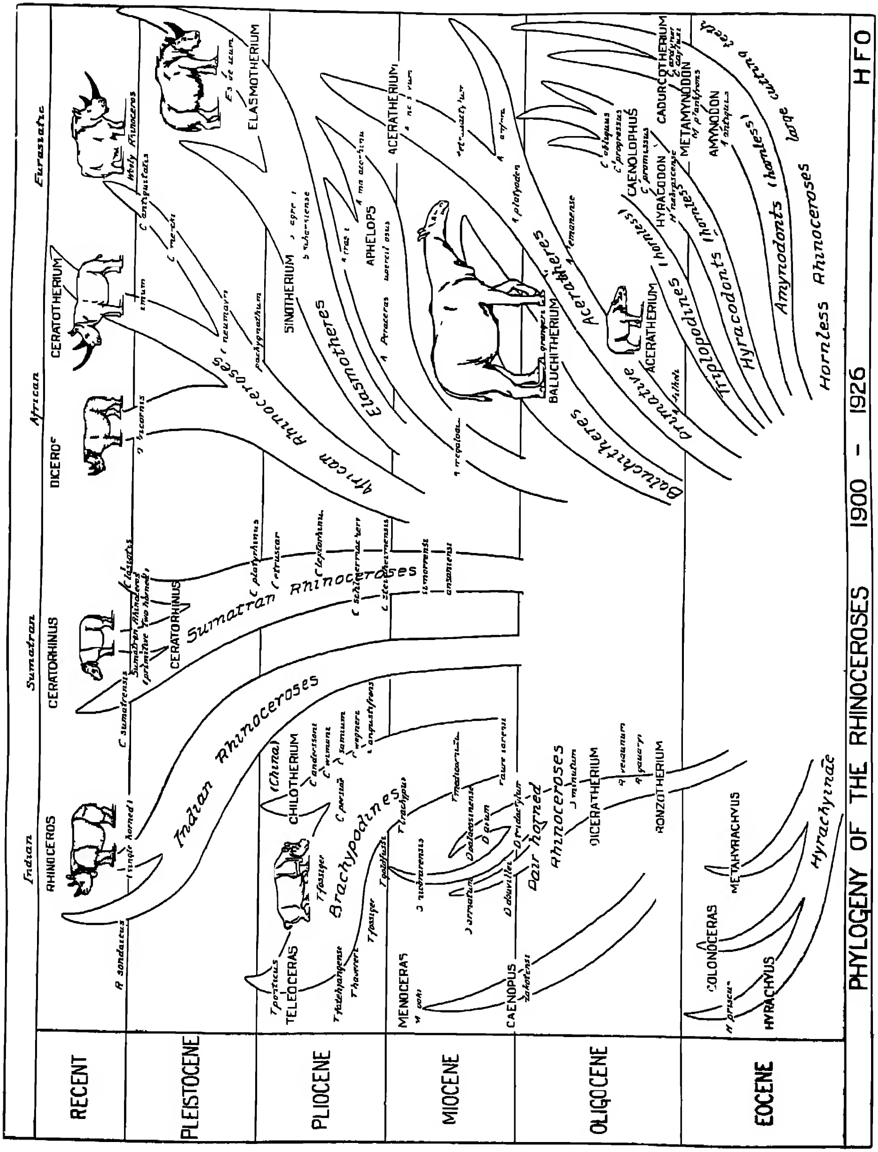


Fig. 9 Evolution of the Elephant Family

Fossils in many parts of the world and from many periods of time show a convergence of the more recent types to fewer and fewer of the more ancient forms, pointing to a common descent with divergence in the course of time After Henry Fairfield Osborn. Courtesy American Museum of Natural History



Reconstruction of Rhinoceros Family History from Fossil Remains of the Tertiary Period

show a somewhat larger animal, with the back of the skull taller, the neck shorter, and the second incisor teeth of the upper jaw somewhat tusk-like. In a later age, spread over several continents, appeared the *Trilophodon,* about as large as the India elephant of today, with longer tusks than have the fossils of the Oligocene period, fewer and larger cheek teeth, and a relatively shorter neck. Fossils of the mastodon show a further advance, although these animals seem to have formed a side branch that became extinct. In the Pliocene occur fossils of the *Stegodon,* which was in several respects intermediate between the earlier mastodons and the true elephants. The genus *Elephas* includes the extinct mammoths as well as the living species of elephants. Fossils of mammoths are found in Africa, Asia, Europe and North America. And the resemblances between these fossils and existing elephants are found not only in the skeletal parts preserved in the rocks, but in other organs and tissues made accessible by the discovery of completely preserved specimens in Siberian ice (see page 34) and in Galicia.

The ancestors of the camels have also left a rather complete series to record the history of their descent (Fig. 10).

Summary and Conclusions

What the fossils and the rocks tell about the past of the earth has a bearing on evolution, as an historical account of what happened, or at least of what the conditions were at various points in time. The facts may be summarized into these general statements:

(1) The fossils in sedimentary rocks show that living beings have been upon the earth for millions of years—at least as long as it took sedimentation on ocean bottoms to form successive accumulations totaling several thousand feet in thickness, for the ocean bottoms to be successively lifted above the level of continents and to subside again dozens of times, and for rivers to cut through hundreds of feet of rock deposits formed in this manner.

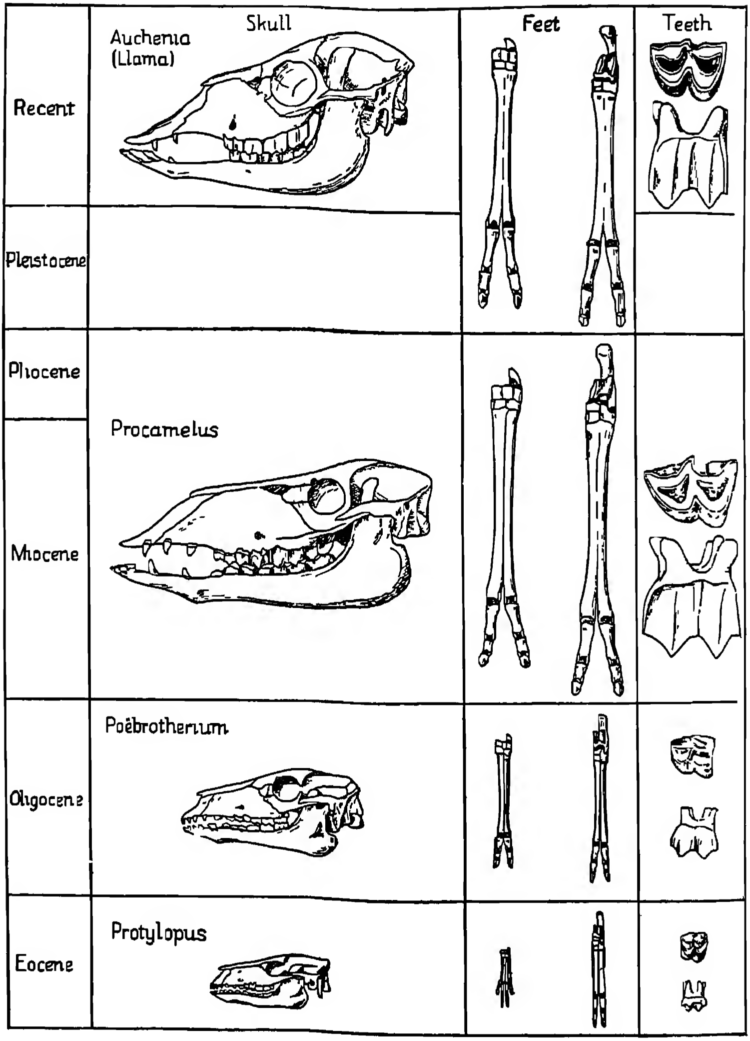


FIG. 10 DESCENT WITH MODIFICATION AMONG CAMELS

From the records left in the rocks ancestors of the present day camel reveal themselves as successively larger animals, with consistent changes in the feet, the teeth, and other parts of the body After Scott

(2) Many forms of plants and animals appeared at successive periods, multiplied and spread over great areas, and finally vanished completely; and other forms have persisted almost unchanged from the time of their first appearance.

(3) The forms that appeared in earlier times were of simpler types than the living plants and animals of later periods; and with the passing of time the successive plant and animal inhabitants of the earth approached more and more to those forms living at the present time.

(4) The succession of life forms and their distribution are such as to agree with a theory of descent with modification; but while the evidence shows that there has been succession with modification, from the very nature of the material, it cannot prove that there has been descent as well as succession.

So confident have students of fossils become of the general facts observed and of the theory of descent-with-modifications, that they have repeatedly predicted the finding of fossils with particular characteristics which had not yet been seen by anyone. From a study of Eohippus and of recent fossils representing the horse family, for example, it was possible to predict that there would be found fossils having intermediate characteristics; and many such were actually discovered in later explorations. This might be compared to the effectiveness of theoretical deductions illustrated by the discovery of the planet Neptune in 1846, the existence of this previously unknown planet having been deduced from the irregularities in the movements of Uranus. Any theory that enables us to predict in advance of direct knowledge, especially in matters that do not themselves yield advance information, deserves serious consideration of its claim to be in accord with reality.

Chapter 3

Resemblances and Differences Among Living Things

THE problem of organic evolution is that of finding an answer to the question, How did the living population of the world come to be what it is? The historical evidence indicates different populations in past ages: the plants and animals have not always been of the same kind as those we see today. What connection is there between the ancient inhabitants and the present-day inhabitants? Are our contemporaries, and we ourselves, the descendants of those former inhabitants, or merely successors? How can we tell whether birds or mammals or plants have descended from ancient forms of life and have become modified in the course of the centuries? There are here really two questions: (1) What is the evidence that life has been continuous from the ancient forms to the present time? (2) What is the evidence that one species has changed into another species?

The Need for Classification

Every normal child begins at some time in his development to ask about the objects that come anew to his notice, "What is that?" In most cases the child is satisfied with a name: That is a tree, that is an insect, that is granite, that is a frog, that is a rosebush. As the individual mind develops, as experience accumulates, discrimination grows. Uncles and aunts come to be known apart, a rug is differentiated from a carpet. Trees in general become fruit trees and shade trees, trees that lose their leaves in the fall and evergreen trees, pines and spruce. Insects come to be divided into butterflies

and beetles and bugs and mosquitoes. One may know several kinds of butterflies apart, several kinds of cats, several kinds of pine. The more our knowledge grows, the more discriminations do we make. We come to need more names for recording our knowledge, for thinking about the many kinds of objects we know, and for the communication of our ideas to others.

It is the mark of ignorance to insist that " pigs is pigs," that bugs are bugs, or that trees are trees. At the same time most of us grow up in the habit of thinking about a species as something fixed, something definitely limited, something sharply separated from other species.

At the level of knowledge which is satisfied to call all creepy things bugs or spiders it is not necessary to define precisely what we mean by a *kind* or a *species*. But when we know enough to start making precise definitions we find that our knowledge stands in the way. That is, the more discriminating one is, the more difficult is it for him to tell exactly what to name a given plant or animal. Whereas the purpose of a species name is to bring together all the individuals that are exactly alike, we are dismayed to discover that the name not only includes individuals that are markedly different from one another, but is often inadequate since a given individual " belongs " just as clearly to two or even more species!

What is a Worm?

The essential problems of classification may be illustrated from a common experience. For many people a " silkworm " is merely a " kind of worm." Of course everybody knows what a worm is. Yet the more one finds out about " worms " the less satisfactory is the name, for it includes altogether too many radically different kinds of animals. It is much more than splitting hairs to say that the " silkworm " is not a worm at all, but a caterpillar. The distinction is very real, and may have important practical

bearings. For one thing, a worm remains only a worm to the end of its life, no matter how long that may be, whereas a caterpillar may in time become a moth or a butterfly. It is, in fact, an early stage in the development of an entirely different kind of animal. It is not necessary, however, to sit by watchfully waiting in order to discover whether the being in question is or is not a worm. Differences between a worm and a caterpillar are easily observable in the outward appearance and in the character of the movements; and the internal structures of the two forms differ still more.

By many people a small snake may be mistaken for a "worm," and again we can understand the reason for such a mistake. Yet anybody who is familiar with either worms or snakes can tell you that the other animal does not belong in the same class, notwithstanding the superficial resemblance. It takes very little additional observation to reveal in the two animals two distinct plans of structure. Indeed, the snake differs more from the worm than does the caterpillar, and is in all essentials more like an alligator, although you might not guess this on first acquaintance.

What is a Species?

According to the traditional conception a species includes all the descendants of a common ancestor or of an original pair of "the same kind." Without stopping to make definitions, this is what most people do actually mean. This supposed common ancestry is something that we can neither know as a fact, nor in any sense "prove" ever to have existed. It is, nevertheless, so reasonable an inference from the facts which we do know about living things, that practically everybody takes it for granted. In the same way, practically all people take for granted the common ancestry of all human beings, whether we accept the story of Adam and Eve or not, whether we accept any theory of evolution or not.

When we see a particular individual living thing in the field, we are of course unable to tell very much about its ancestors. For all we know, that worm which we see crawling around the edge of that stone never had any parents or any other ancestors. For all we know, it may have been created right there just before we appeared upon the scene. We may have positive knowledge about the origin of certain individual plants and animals. That dog is one of a known litter; we grew that corn from seed saved from last year, and so on. From this limited knowledge we extend our interpretation to all living things. We manage our affairs *as if* every living thing did actually come from parents, and *as if* all of the same " kind " did actually have common ancestors (Fig. 11).

How are Species Related?

How is it, however, when we compare plants and animals that do not resemble each other so closely? For example, the fox and the dog are different enough to get different names from ordinary observers. Why do we nevertheless believe that they are " related "? In the case of human families, we speak of relationship only, as a rule, when we know something of the actual facts as to parents, grandparents, and so on. We should not ordinarily be satisfied to assert a relationship between a Mr. Morton in one state and a Mr. Lee in another state merely because both happen to have hair of the same color, or because we notice a resemblance in the shape of the mouth.

What warrant is there for saying that any species of animal is related to another? It is here of course impossible to obtain family histories. We have to find our evidence in other directions. We use in the first instance the same assumptions that we make when we call two distinct plants by the same name, for example, two pine trees, two violets; or when we say of a particular animal the first time we see it, " that is a sheep," or " that is a bear." The only *facts* we know directly are particular individual objects —

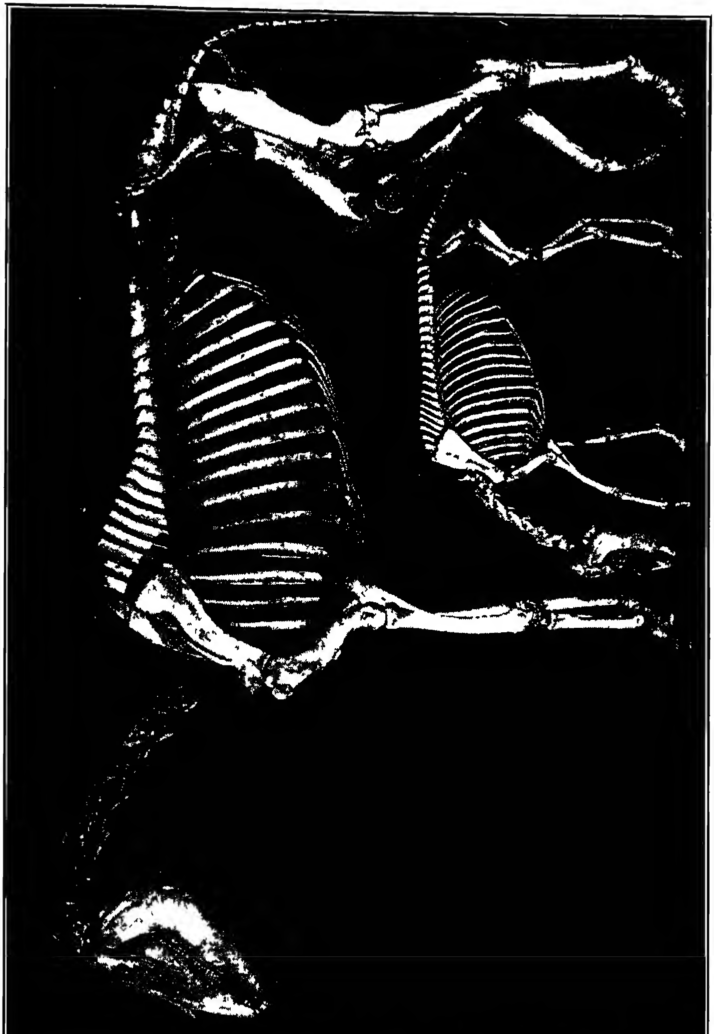


Fig. 11 Horses and Horses

By calling the Percheron and the Shetland pony both "horses" we assert a common ancestor However much this ancestor resembled either of these present-day types, it must have differed also from both — unless we assume that one of these represents the ancestral type from which the other is a descendant. Photograph of mounted skeletons, courtesy of the American Museum of Natural History.

particular plants, or animals, or persons. However many acquaintances you may have, you never know "mankind" or "the human race." We know only single persons. We group individuals into species on the basis of their resemblance. We can group species together — and assume "relationship" in the sense of *common ancestry* — on exactly the same basis.

The other side of this problem is seen when somebody points out consistent *differences* among individuals that we have been lumping together under one name. Consider, for example, the very numerous plants, growing over a large area, that you and I call "violets" and that we assume to be "related." Along comes a botanist and tells us that all of these plants which we have been satisfied to call by one name represent at least twenty different "species." When he calls our attention to the details we acknowledge that the differences are clear enough. Are all of the so-called "violets" still to be considered "related" even if we agree to give special or specific names to each of the twenty or more different "kinds" that we can distinguish?

Ordinary thinking includes the suppositions that (1) all the individuals that resemble one another sufficiently are members of the same species; and that (2) all the members of a species have a common ancestry. The idea of organic evolution includes the further supposition that several such groups-of-individuals or "species" may also have a common ancestry.

If we cannot trace back the family histories, we can at least consider the question of how close a resemblance there is between the red maples and the sugar maples for example. We can then try to decide whether the resemblances are sufficient to satisfy the assumption that all of them have descended from a common ancestor. If we compare an eagle with a jellyfish we find the differences so striking that we have difficulty in finding similarities at all. If we go further and try to find out what *all* living things have in common, numerous resemblances — and corresponding sugges-

tions of relationship — gradually force themselves upon our attention.

Let us, then, look at the workings of living things in general by attempting to contrast them with non-living things.

Living Things are Distinguished by Form

The plants and animals with which we are most familiar are commonly recognized as belonging each to a particular species or kind. We recognize the group in which we would place a given individual by the general form. We can recognize a particular kind of tree or a particular kind of shrub, even at a considerable distance, by the general form. In many species we recognize great variations in coloring while the form remains fairly constant, so that we speak, for example, of the red fox and the silver fox. In some species there is great variation as to the size which the individual may attain, although the general shape remains almost uniform. In some species, as the common dog, there are so many "varieties" that we should be disposed to classify some of the types as totally distinct species. There is more difference, for example, except for our familiarity with the animals, between a mastiff or a greyhound and a Pekinese or a bulldog than we commonly observe among such distinct species as wolf and hyena. Nevertheless, it is a part of our ordinary experience that a living individual, whether plant or animal, has a particular form which is common to all members of the species and is thus distinctive of the species.

This fact of a distinct form is true of all living things, although it is not confined to living things, for many of the non-living objects found in nature also have characteristic shapes — for example, crystals of various kinds, volcanoes, river deltas, and so on. Most artificial objects also have distinct forms.

Organization

A statuette of an elephant may be said to have the general "form" of a natural elephant. There are of course important differences in the structure of the two and in the chemical composition. Even, however, if we could make a statuette consisting of the same chemical substances as are found in a living elephant, there would be great differences in the structure, since the living thing, whether plant or animal, has the characteristic of structure which we call *organization*. The many distinct parts of which it consists have particular relationships to one another, and especially to the workings of the being as a whole. It is for this reason that individual plants and animals are sometimes spoken of as *organisms*, that is, structures consisting of organs or instrumentalities. The thought is that each part performs some activity or serves some function in relation to the totality.

Human skill has constructed a great variety of mechanisms or machines in which the different parts serve special purposes, and which might therefore be thought of as "organisms." There is, however, more to a living thing than any artificial contrivance can duplicate.

Growth

All the living beings that have been observed have the capacity to increase in size or grow. It is common to think of growth as characteristic of life for this reason, although certain non-living things are also capable of growth, in a proper sense. For example, a crystal in suitable surroundings steadily increases in size while maintaining its characteristic form. An icicle may grow when there is a certain alternation of thawing and freezing. Sand dunes and tide beaches may be said to grow by the accretion or piling up of materials brought by wind or wave.

The growth of a plant or of an animal appears nevertheless to be fundamentally a different kind of process from the

growth of a non-living crystal or sand pile. There is first of all the fact that whereas a crystal or sand pile grows by the addition of similar material, the plant or animal takes from its surroundings entirely different materials and converts them into its own substance. This process of changing foreign substance into itself, which so far as we know is to be observed only in living bodies, is called *assimilation*, or making alike. Moreover, in a living plant or animal, this assimilation takes place throughout the whole living structure and not merely upon the surface. The baby, for example, takes in materials derived from a cow, from a wheat plant, or from a potato plant, and converts these materials into what is at last indistinguishable from baby stuff. There is an increase of baby stuff at the expense of these foreign substances which we call food. And exactly the same kind of process takes place in all living things. This assimilated material brings about growth, not by a mere external addition, or by a filling in as one would cause a mail pouch to expand by stuffing more into it, but by enlarging each of thousands or millions of tiny units of which the organs are made up.

Furthermore, whereas the growth of a crystal or any other non-living body can continue as a result of a steady supply of suitable material, the growth of a living animal or plant involves not merely the appropriation of suitable " foods " but also a steady output of waste substances. That is to say, there is involved in the assimilating process a large number of chemical activities which bring about both the formation of living substances out of the income or food, and the creation of a large number of substances that are not used by the living organism and are discharged to the outside.

Metabolism

The totality of these many chemical changes that go on within living substances is called *metabolism*, that is, " working over "; and it includes the building up of living matter and its breaking down.

There is of course a limit to the growth of most plants and animals. Among human beings, for example, we recognize that the individual reaches a certain size and may remain for a long time at this point with very slight variations from day to day. Among other living things, such as certain kinds of trees and certain kinds of fish, growth seems to continue as long as life lasts. Whether the growth is rapid or slow, or even if the size is practically stationary, the living being must continue (if it is to remain a living organism) to take in material from the outside and to discharge waste substances to the outside. The chemical changes going on during such a stationary period are essentially all of the same kind as those going on during growth. Moreover, the chemical processes occurring in living things during growth and during maintenance are essentially the same in plants as in animals.

Different then as the eagle may be from the jellyfish in outward appearance and in the character of its performances, there are certain fundamental similarities. Each has a form characteristic of its species. Each starts life as a very tiny individual — too small to be seen without a microscope. Each grows from this to a form and size characteristic of the species. Each takes in various materials from the surroundings and throws out various other substances as part of the fact of growing and keeping alive.

Movement

One of the most striking facts about familiar animals is that of movement. Indeed, to most people movement is so closely associated with the idea of animal life that we are apt to assume life wherever we see movement in nature. For the same reason we are apt to overlook life among many plants and stationary or sluggish animals. The capacity to move, however, is present in all living things, plants as well as animals. The movements seem to arise from happenings within the organism, as distinguished from such movements

as are brought about by the application of an external force. For example, a young fledgling falling out of its nest is moving in the same way as an apple falling off a tree or a leaf fluttering in the breeze — that is, through the action of some external force. A worm crawling upon the ground, however, or a gnat darting through the air, is thought of as moving because of some happening on the inside. This kind of movement, in plants and in animals, is found by observation and experiment to be due to contractions of the living substance. We can see extreme manifestations of this kind of contraction in the work of the muscles or flesh of higher animals.

We do not ordinarily observe the movements of plant structure because their movements are very slow, and especially because they take place on such a small scale that we should not be able to see them even with careful watching, unless we used a microscope. There are many plant movements, such as the expanding of a flower bud, or the curling of a tendril, or the twisting of a seed pod, which are observed without great difficulty. Such movements are in large part due not to the contraction of the living substance or protoplasm, but to uneven growth, or to uneven drying or absorption of water.

Movements of this last kind as well as other movements are to be found in non-living substances, especially in artificial contrivances and in chemical substances which bring about more or less violent movements in the course of their changes. In the latter class are the various kinds of explosions which we can bring about by means of special preparations.

Irritability

Another characteristic of living things is seen in our own sensitiveness to what is going on around us. The prick of a pin, a breath of cold air, the taste of sweet or sour, the sound of passing traffic — these represent our own sensitive-

ness to a great variety of activities that seem to be going on outside the organism. Every organism is sensitive to such activities and changes though not all to the same degree. This sensitiveness we discover through observation and experiment to lie in the constitution of the living matter itself, and is sometimes spoken of as *irritability*. Plants are irritable as well as animals, as we may find from close observation, although not all living things are equally sensitive to the same disturbance, and although they do not all respond in the same way when they are disturbed.

Any one of the larger animals with which we are familiar is likely to respond to disturbance by some kind of movement. When you approach a bird that is feeding peacefully on the ground, the bird takes flight before you have time to reach it. If you pull an animal's tail it may perform a variety of movements, some of which may amuse you or worse, and some of which may bring the animal out of your reach. Even a young baby performs a violent movement — that is, a contraction of muscles — when something very warm touches his skin. A sudden illumination brings about muscular contraction around the pupil of the eye. The sudden introduction of something "sour" brings about violent contractions in the muscles of the face. In former times it was well known that a relatively light touch on the flank of a horse might start rapid contractions in the animal's legs.

Movement such as we can see directly is not the only means by which a living thing can show its irritability. In our own bodies, for example, the taste of "sour" need not produce any visible movements but does produce chemical actions that show themselves in a flow of saliva. In the more familiar animals there seems to be a greater degree of irritability in certain limited regions which we sometimes call special sense organs — the eye, the ear, the tongue, the lining of the nose, and so on. The high degree of irritability in these organisms is associated with the presence of a special kind of living tissue which we call nervous tissue. It has not been possible so far to find anything in plants corresponding to

this nervous tissue or to special sense organs, but it has been possible to find that all plants are irritable to a great variety of disturbances or stimulations. For example, by turning an ordinary house plant, as it stands near the window, half way around every two or three days, we can find that it is sensitive to the direction from which the light strikes it. In such a case, the plant manifests its irritability by changing the direction of its growth. By means of similar experiments we can show that the plant is sensitive to the direction of gravity, to various chemical substances, to electrical stimulation, to water, and to mere contact — the same as ourselves but not to the same degree. On the other hand, sensitiveness to light varies a great deal among different organisms so that many plants respond to an amount of light which our eyes cannot observe, and many insects are sensitive to ranges of the spectrum that our eyes cannot perceive — just as dogs are sensitive to odors which most human beings cannot distinguish or even detect.

Chemical Response

A striking example of a reaction to outward stimulation in a form other than contraction was brought out in the studies of Metchnikoff, Behring, Ehrlich, and other. When a foreign substance is introduced into the body of a warm-blooded animal a special kind of chemical change is brought about. It is possible to show that the new substance formed is present in the blood. It can also be shown that the new substance is specifically related to the chemical nature of the stimulating foreign substances. It is upon this principle that *anti-toxins* have been developed for the combating of diphtheria and other diseases.

Fitness

We know of course that irritability is not confined to living things. Many of our high explosives are set off by a

comparatively slight disturbance from outside. In photography we use a great many substances that undergo chemical change under exposure to light. In these cases, the response to the disturbance results in the destruction of the sensitive substance. In an organism, however, the response to a disturbance is, generally speaking, of a kind that tends to help the organism in some way, or of a kind that tends to preserve it from further injury.

When a moving body approaches a bird, the bird flies away. That is, the stimulation (in this case through the eye) brings about a response which in general tends to save the animal from possible injury. On the other hand, if the bird catches sight of a very small moving object, such as an insect or worm, the movements of the bird's muscles are such as tend to capture the small body as possible food. When a dog is annoyed, he snaps in the direction from which the disturbance comes. When a hedgehog is disturbed, it bristles out in the direction from which the irritation comes—although it does not, as a common superstition tells us, throw out its quills towards the possible enemy. From the simplest animals like the ameba to the most complex the general fact holds that response to stimulus is on the whole, though not uniformly, of a kind that tends to protect, or to obtain something necessary to continue life. Adaptation, while never one hundred per cent perfect, is characteristic of all living bodies. These two general facts, namely, adaptation and imperfection of adaptation, are very important for understanding of life, and have a particular significance for the question of evolution.

Origin

Man with his ingenuity has succeeded in building machines that show remarkable adaptation of parts to the maker's purpose, remarkable complexity of structure in which each detail fits in with every other detail. He has constructed mechanisms that are remarkably sensitive to

light or to sound or to touch or to chemical changes, and even to forms of energy and to processes which he is himself unable to detect through his unaided senses. None of these mechanisms, however, shows any special fitness to preserve itself or to maintain itself. Moreover, none of these artificial contrivances resembles a living thing in being able to *reproduce* itself. So far as we know, all living things come from preëxisting living things. Where we know nothing at all about the parentage of a plant or animal we assume nevertheless that the individual originated exactly as did other individuals of the same kind in the past. This fact of generation has been universally observed wherever the origin of a new individual plant or animal could be observed at all. We therefore assume it to be true of all living things today, even where it is impossible to observe directly the origin of each particular individual. We further assume that this succession of individuals from generation to generation through the processes of reproduction will continue indefinitely into the future. Finally, we project this general fact backward in time and assume it to have been true of all living things in the past, even if we do not know when, or where, or how the series started in the first place. Here again we have an example of taking facts which are known to us in only a limited number of instances and drawing from them the feeling of certainty in regard to the past and in regard to contemporary events about which it is absolutely impossible to *prove* anything.

Genus, Species, Varieties

We have assumed (page 51) that a number of beings are "related" in proportion to their resemblance. Accordingly, we should say that all living things are related to one another in so far as they do resemble one another, that is, in so far as they are *organisms* with all the characteristics of living things. This resemblance does not, of course, "prove" that they are indeed related or that they have, in fact, had com-

mon ancestors — in other words that there has been descent of one living form out of a different living form, or evolution from simple forms to more complex forms. It is conceivable, for example, that each particular kind of living being came into existence through a separate act of creation, and that there is no other connection or relationship between one species and another except the simple fact that they are all made up of living things.

The difficulty of this supposition of separate origins appears when we try to describe any species of plants or animals.

It was long ago recognized that the common names given to various kinds of familiar plants and animals were not satisfactory. First of all, common names are not very definite and may mean one group in one region and something quite different in another region. In the next place, as we have already noted in the name violet, each common name often includes several distinguishable *groups* of individuals. Such a group is commonly called a *genus*. According to the system of naming plants and animals developed by the Swedish scientist Linnæus, each name consists of two parts, the genus and the species names, as we should say red maple, sugar maple, silver maple. Maple is the genus and the qualifying word red, silver, etc., represents the species. The use of two names for identifying individuals, the family name and the personal name, illustrates the same principle. In defining a word it is also standard practice to give the genus and the species. We say, for example, a keg is a small (species) barrel (genus); and that a tun is a large (species) barrel (genus). We say that a barrel is a container or vessel (genus) made-with-staves-and-hoops (species).

While we understand then what we mean in principle by genus and species, we are nevertheless exposed to confusion when we attempt to speak of the actual plants and animals with precise definition of " kind." The word " corn " for example means what we call " rye " in some places and any kind of " grain " in other places. Moreover, in this country where we can fit the word as a rule to the " Indian

Carl Linnæus

Sweden 1707–1778

corn" or maize type of plant, there are several hundred different kinds or varieties that are properly included under the name, even if we use the "scientific name"—*Zea* (genus) *mays* (species).

Sometimes the distinction is made between species and varieties, and this distinction is often helpful. It does not, however, relieve us of the difficulty of saying just exactly what we mean by a species, or of saying just what is included by any given "kind" of plant or animal. In thousands of cases that have been carefully studied *varieties merge into one another,* and *species merge into one another.* So much has this been the case wherever enough study has been applied to any group that those who know most about any family of plants or animals are disposed to conclude that *the species as such does not exist* as a definite fact of nature. We know as facts only particular individuals, and we group together under one name all the individuals that resemble each other sufficiently to be conveniently considered by us as a unity. Our own convenience or our own skill in discriminating among similar individuals comes at last to be the only test. For some purposes we are satisfied to take more general resemblances into account, as when we speak of "all animals" or of "all backboned animals," or of "all birds."

It should not be necessary to observe, each time some such collective expression is used, that nobody can possibly know the whole group which the name is supposed to include. That seems to be common sense. We need still to be reminded, however, that such names do not stand for concrete realities, like "the friend of Androcles" or "the Charter Oak." They stand for abstract ideas of "species" or whole classes which, from the nature of our world and from our own natural limitations, *we can never grasp as facts* (Fig. 12).

Our own experience tells us that, although no two cats may be alike, all cats are enough alike to be classed as cats and to be distinguished from leopards, let us say, or tigers.

Our own experience recognizes not only differences but similarities. Yet no individual's experience is ever sufficient to discover that the animals of a given "kind" with which he is familiar grade off through practically imperceptible differences into other groups for which a different name seems appropriate (Fig. 12).

The Succession of Forms in Time

Even if we could come to some satisfactory definition of species, so that we could keep each kind of plant or animal distinct and separate from all other kinds, we should have another difficulty. The supposition that each species arose from a separate act of creation leads us to the idea that such creation was not an act finished at some past time, but one going on continuously. All the facts that we have about the living beings of former times show without any possibility of doubt that there lived at various periods plants and animals of kinds that no longer exist. Some of these species came into being at a particular time, increased in numbers of individuals and eventually died out. If we assume that each species arose as a separate act of creation we can understand that some, at a particular time, need have had no ancient ancestors. We can also understand that a species might die out without leaving any descendant. The facts, at any rate, indicate (1) that new species did make their appearance from time to time, and (2) that there now exist plants and animals of kinds which are distinct from any for which fossil remains can be found in the oldest or even in some of the more recently formed layers of rocks. It is true, of course, that the fossils represent only a small fraction of the plants and animals that lived at any given period; and of course the fossils which have been found represent probably only a small fraction of the remains that still lie buried in the rocks.

Further, if we suppose that new species were created from time to time, we should have no reason to expect that

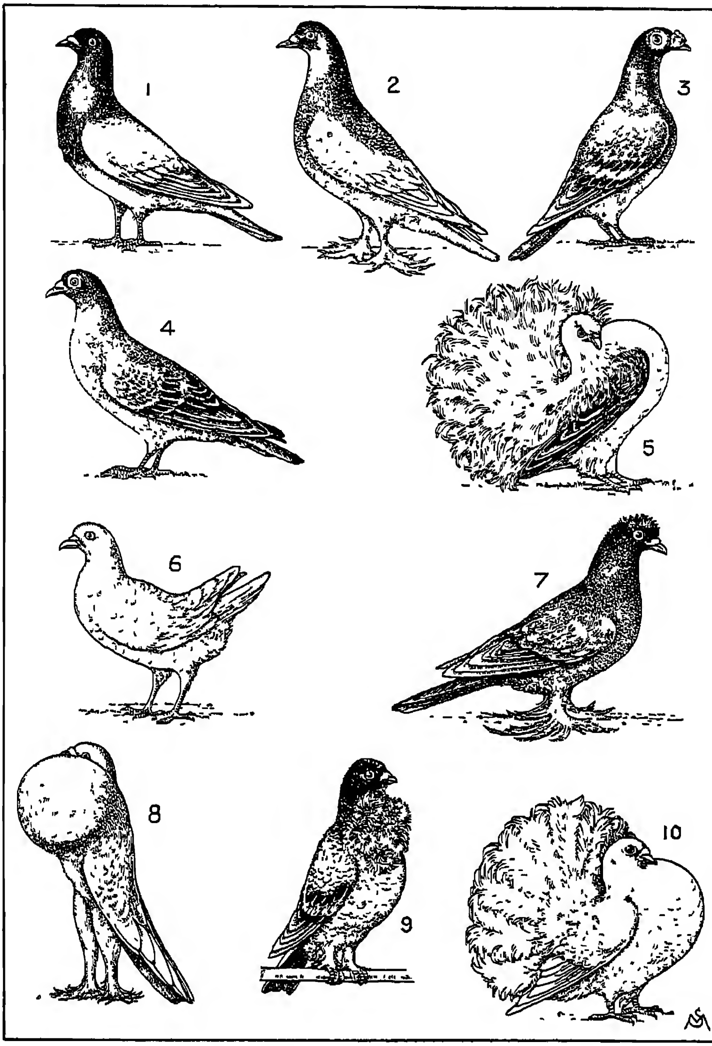


FIG. 12. VARIETIES OF CULTIVATED PIGEONS

Over two hundred varieties of pigeons breed true More than a dozen types differ from one another so much that, were their history not known through the records of actual breeding, every observer would unhesitatingly call each a distinct species. 1, Silver Runt; 2, Muffed Tumbler, 3, Dragoon, 4, Homer, 5, Saddle Fan-tail; 6, White Maltese, 7, English Red Trumpeter, 8, White Pouter; 9, English Owl, 10, White Fan-tail From Gruenberg, Biology and Human Life, published by Ginn & Company.

one type was created before rather than after a certain other type. Some kind of fish, for example, or fishes in general, might have been created either before birds or after birds. Sea stars could have been created after lobsters as well as before lobsters. There is nevertheless a remarkable coincidence between the actual succession of fossils representing successive periods of time and the succession of forms which the idea of evolution would lead us to expect. *New species or forms appeared after similar but relatively simpler ones already existed.*

The Test of a Species

One of the oldest ideas about the permanence of species is found in the assumption that the members of each species will breed among each other, but not with members of another species. This is indeed the basis for the notion of "varieties," as distinguishable subdivisions of a species, which are yet unrelated to other species. When the various breeds of dogs or horses are crossed, we decide that they represent varieties, not species. When the horse is crossed with the ass, we continue to call the horse and the ass separate species, and fall back upon the sterility of the mule as evidence that the two species are really not fertile although thousands of mules carry on their dull but useful existence.

There are other cases of crossing that are even more striking, however. Some of these inter-species crosses are those between the finch and the canary; between domestic cattle and the bison; between the wolf and domestic dogs; between the camel and the dromedary; between the zebu and the yak; between the sika deer and the red deer; between the goose and the pheasant. Recently there has been reported a successful cross between the radish and the cabbage. Different strains of what is unquestionably the same "species" sometimes prove to be sterile when mated. This does not destroy the usefulness of the notion of species. On the other hand, we are not warranted by the facts of such crossings

in assuming that species are fixed and perfectly isolated from each other.

Measuring Resemblances

When we try to picture the relationship of a particular individual to his uncles and his cousins and his aunts, we develop a figure which is sometimes spoken of as a "family tree." If we examine the actual individuals which such a tree represents, we find a certain connection between the degrees of relationship and the degrees of resemblance. It is a familiar fact that twins resemble each other more than do ordinary brothers and sisters, and that brothers and sisters resemble one another more than do cousins. Careful measurements have been made of thousands of boys and girls, men and women, with respect to large numbers of facts like stature, pigmentation, proportions of the head, the limbs, the nose, and so on. Through the comparison of many such measurements it has been possible to find some scale for the degree of resemblance. The mathematical calculations by which such resemblances are measured are rather complicated, but for our purpose it is enough to consider degrees of resemblance measured on a percentage scale. On such a scale the resemblance between identical twins would be from 90 to 93 per cent. Brothers and sisters would resemble each other 50 per cent. Cousins would resemble each other approximately 20 per cent.

The Tree of Life

While we cannot measure in the same way minor degrees of resemblance, we can apply the same principles to our classifications of plants and animals. Whenever we attempt to arrange the various kinds of plants and animals according to the degrees of resemblance which they show, we invariably produce a figure suggesting roughly a "tree" (Figs. 13 and 14). In such a tree the types that most closely resemble one another are represented by twigs placed close

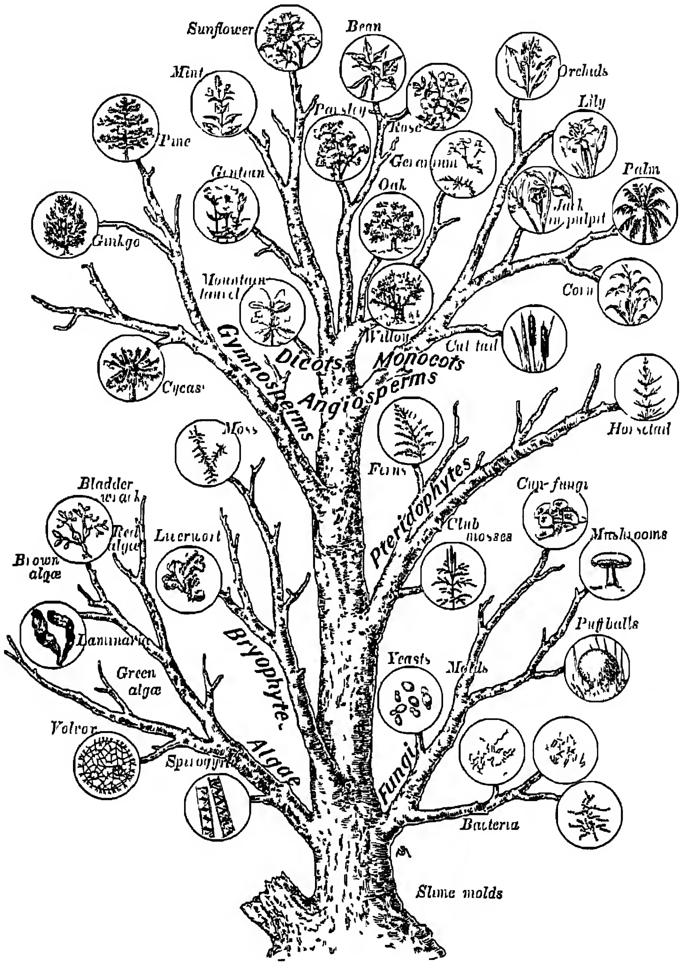


FIG. 13. GENEALOGICAL TREE OF PLANT LIFE

An attempt to classify plants according to their resemblances results in a tree-like arrangement. The more closely related two forms are, the closer together would they be on a given branch *Lower* and *higher* mean nearer to or farther from a common ancestral type From Gruenberg, Elementary Biology, published by Ginn & Company

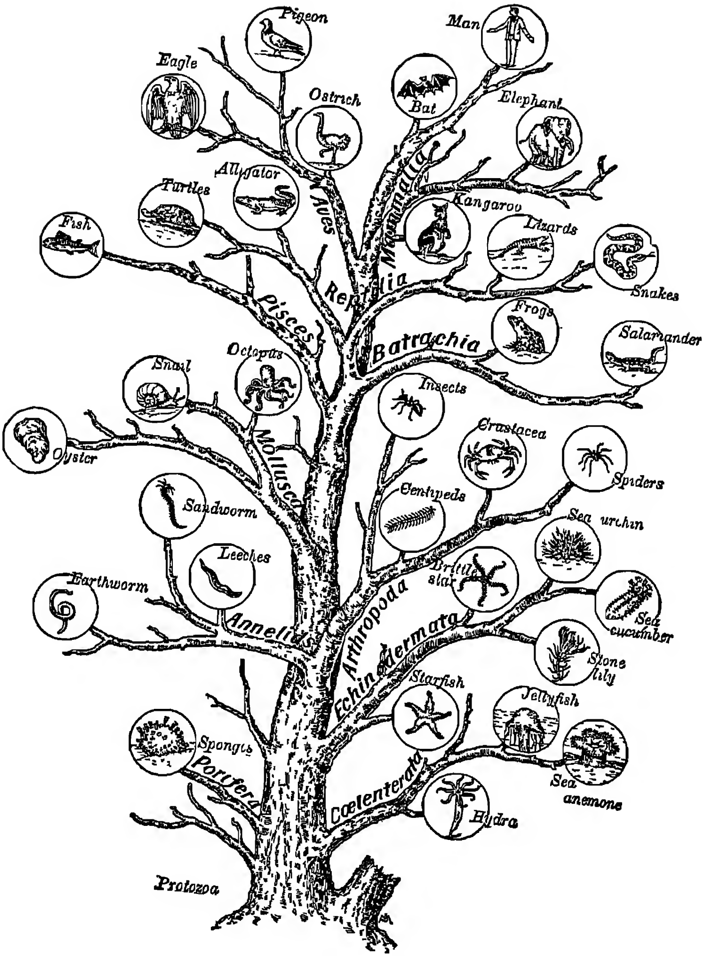


FIG. 14. GENEALOGICAL TREE OF ANIMAL LIFE

This diagram is intended to suggest the common origin of all animal forms, with the constant progressive departure from ancestral types, now in one direction and now in another Of course only the main branches are shown, as in the corresponding survey of plant life, Figure 13. From Gruenberg, Elementary Biology, published by Ginn & Company

together. Forms that are more and more distinct are represented by larger twigs or branches that spread farther and farther apart.

On the chart of a family tree of an actual human family we could blot out the connecting lines and certain of the individuals. We should then have left the records of a dozen or a score of persons whose *history* shows them to be related, but whose *appearances* would lead no one to suspect such a relationship. If we build up a scheme or family of known plants or known animals according to observed resemblances, the types represented by the various twigs appear quite distinct. Yet the connections, while not really observed in all cases, are of a kind that correspond to the known process of divergence or spreading out of forms in the course of descent (see Figs. 7 and 9).

Continuity and Divergence

We do not assume relationship from mere resemblance. Certainly we do not suppose that a shoe box is " related " to a desk because it has the same general shape, or that a window-pane is " related " to an inkwell because both consist of glass. The idea of relationship or descent from common ancestry we confine to living things because it is characteristic of living things to originate from parents — that is to say, to have ancestors. We accept then the principle of descent from ancestors, or the origin of life from life. We accept further the principle of *heredity*, or the idea which is commonly but inadequately expressed in the statement that " like begets like." The exact processes by which resemblances between parents and offspring are brought about have been discovered only since the end of the Nineteenth Century. It has long been proverbial that we cannot " pluck figs from thistles," or " grapes from thorns." The first of these principles, " all life from life," has been thoroughly established and has become widely accepted. Only the most ignorant persons still expect horsehairs to turn into worms, or spoiled cheese into

maggots. The second of these principles is so readily observed that only the simple-minded hope to change geese into swans. Whether one is familiar with biology or not, he would be astounded to see pumpkin seeds grow into pine trees, or a cow give birth to kittens.

Our very familiarity with the idea that like begets like stands in the way of our recognizing the equally important and equally established fact that *offspring are never exactly like their parents.* It makes difficult the thought that new kinds of plants and new kinds of animals do actually appear, not only at rare intervals as "freaks," but regularly in every garden, along every roadside, in the ocean, in the woods, on every farm. We notice monstrosities, especially if they are unable to maintain themselves, or to reproduce themselves. We do not notice the more frequent appearance of new combinations of characters that are not very striking at first but that may nevertheless give rise to a new strain or breed of plants or animals. There is involved here a third set of facts. There is resemblance between parents and offspring, like does indeed beget like: but the resemblance among the individuals having the same ancestors is never perfect. Nor is the resemblance between individuals and their ancestors perfect. Parents resemble their offspring on the average more than they do strangers, but less than do brothers and sisters. In general, we measure the degree of relationship by the degree of resemblance.

This brings us to a fourth set of facts: offspring differ from their parents and their ancestors. There is not only descent from ancestors, but also divergence in form, color, size and other qualities which are characteristic in the successions from generation to generation.

These facts together constitute the very essence of the principle of organic evolution — namely *descent with modification:*

(1) So far as we know, all life comes from previously existing life; there is continuity of life, through reproduction, from generation to generation.

(2) There are the facts of heredity; individuals resemble one another according to the degree of relationship.

(3) There are the facts of variation; not only do individuals of the same ancestry differ among each other, but offspring differ from their immediate parents.

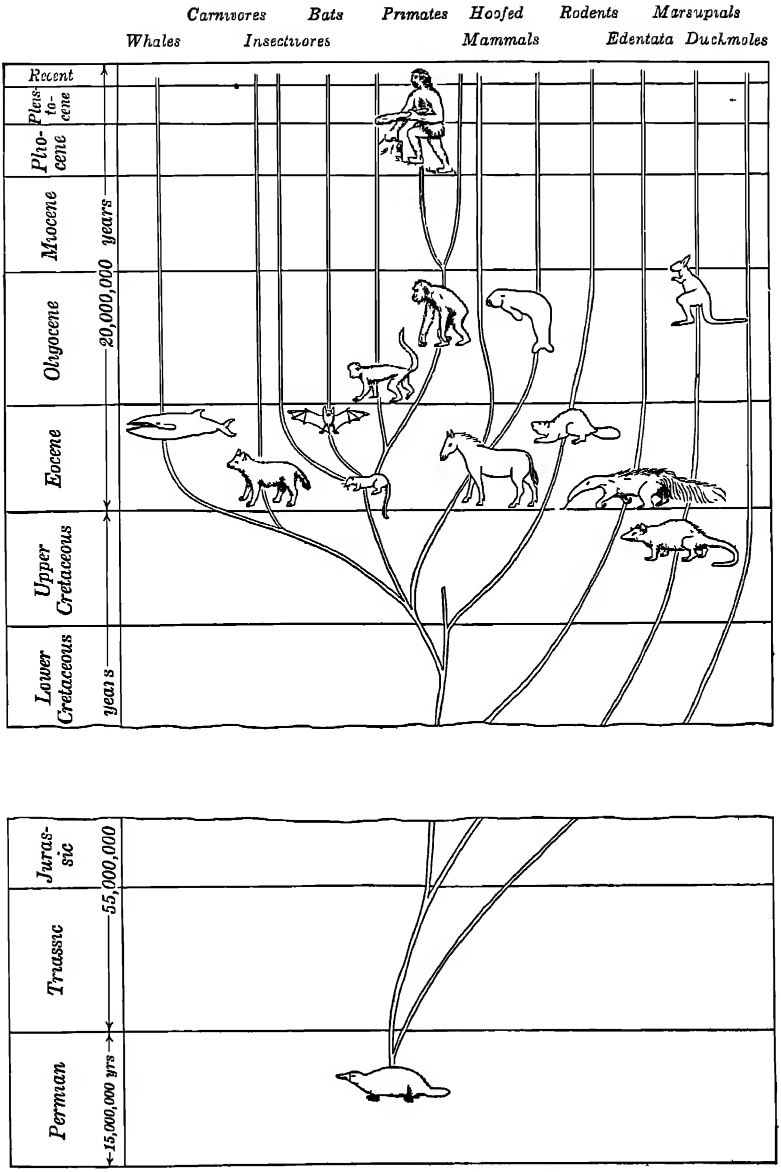
(4) Diverging individuals become the ancestors of diverging strains, breeds, varieties, or eventually species.

Evolution Familiar to Everybody

We may be able to imagine the opposite of each of these sets of facts. But the alternatives do not fit our actual experience. We can imagine living things originating anew out of non-living objects in as whimsical an order as we please — or out of nothing at all. We can imagine plants and animals, old kinds or new kinds, "created" right on the spot with no living thing to precede each new individual. But this picture is contrary to all of our positive knowledge about plants and animals.

We can imagine living things without the facts of heredity. While acorns arise from oaks and give rise under suitable conditions to new oaks, we can imagine oak trees giving rise to opossums, or any kind of living thing giving rise to almost any other kind without restriction. But that is not the way the plants and animals which we know do actually behave.

Again, we can imagine all the individuals of a particular kind being *exactly* alike — not only offspring like parents, but all members of a species exactly alike, and individuals quite indistinguishable from one another, except perhaps for age or sex. Indeed, in many species of plants and animals this is so much the case that it is almost impossible to distinguish one individual from another, at least by casual inspection. Among the very simplest plants and animals, and among certain kinds of insects, the variation from individual to individual is very slight. Yet our common experience is such that, along with the facts of resemblance in



RADIATING ADAPTATIONS AMONG MAMMALS

Fossils record divergence among mammals in the course of millions of years, resulting in the appearance of several classes with many species adapted to a great variety of environmental conditions. Adapted from Osborn and Gregory.

proportion to degrees of relationship, there are also differences that make each individual practically unique.

We can imagine the inhabitants of the earth to remain practically unchanged from generation to generation, from century to century. This is conceivable, whether individuals in a given species differ from each other much or little. The facts of experience, however, show us that among the offspring which differ from their parents are some that initiate new lines, which remain consistently different from the ancestral stock.

Throughout centuries observers and philosophers have felt convinced that new species appear from time to time and must in past ages have descended from ancestors somewhat different from themselves. There has never been, until our own times, a sufficient accumulation of accurate observations to tell us whether new species gradually depart from the ancestral types, or whether a new form arises by means of a rather sudden departure from the parental form. Much of the speculation and uncertainty and confusion have come from the lack of knowledge on this point; but whoever knows the facts is satisfied that there has been descent with modifications.

Classification of living things is a highly artificial process, since we cannot know species or classes as existing entities. Yet it is by no means arbitrary. The resemblances that lead us to group some forms together and the discriminations by which we separate nearly similar individuals into subdivisions represent real facts, however we may account for them. The persistent study of plant and animal forms leads us to group them into arrangements that suggest progressive divergence from common ancestors in exactly the same way as a family tree shows divergence from common ancestors. Succession by descent with divergence constitutes the essential facts of organic evolution and is thus supported by the facts of resemblance and difference among living things.

Chapter 4

The Insides and Workings of Living Things

AMONG plants as well as among animals there are many resemblances that lead to confusion, and sometimes to serious mistakes. When people mistake poisonous mushrooms for kinds that are fit to eat, or when they mistake injurious berries for harmless ones, they are identifying on the basis of superficial resemblances. In many cases it is practically impossible to make up simple rules that will enable untrained persons to distinguish one such group from the other. In general, however, we can understand that a reliable classification must take into account more than outward appearance.

Many of the superficial resemblances that we see in living things appear to be related to the conditions of living, rather than to more fundamental characteristics (Fig. 15). Many of the animals that live in the water, for example, have what we may call a "fish-like" form, and yet are totally different when we come to examine their structure more carefully (See Fig. 31, page 106). It is necessary to go below the surface and to base our groupings on the *plan of structure,* or on details that are not likely to be influenced by outward factors. The organs of reproduction, for example, are more characteristic generally than the vegetative organs of a plant. The tubes and fibers found on the inside of leaves and stems are more characteristic than the shape of a leaf or the color of a flower.

Plans of Structure

The difficulties of the earliest students of classification grew in a measure from the failure to recognize these different plans. To arrive at this much insight, it was first necessary to do a great deal of comparing, of critical checking of details of structure. One of the first attempts to compare in detail the structure of one type of animal with that of another was made three hundred years before Darwin pub-

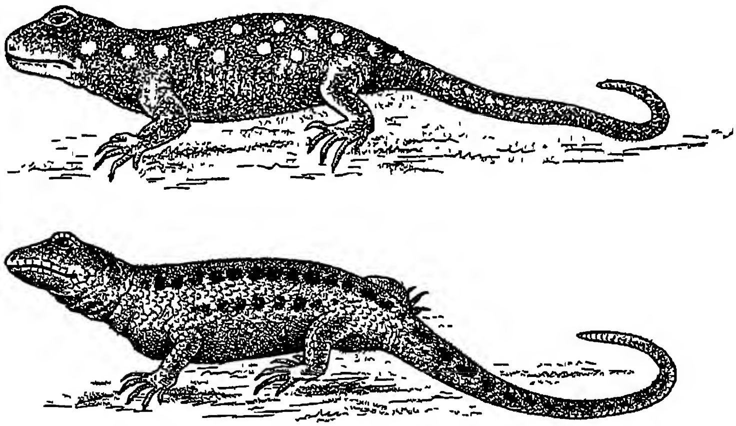


FIG. 15. MISLEADING RESEMBLANCES

The general appearance or form of a living thing may furnish a misleading resemblance to one of a different class The mountain lizard, *Lacerta vivipara,* is a reptile, related to snakes and turtles, whereas the newt, *Ambystoma maculatum,* is an amphibian, related to frogs and toads

lished his *Origin of Species,* when the French naturalist, Pierre Belon, published comparative descriptions and pictures of many animals, and studied especially the bones of birds and of man in corresponding postures. Over two hundred years later a French court physician and anatomist, Vicq D'Azyr, made a more detailed comparison of the limbs of quadrupeds and of man, showing especially the precise correspondence between the more important muscles of the arms and legs. He made also the most detailed study of the structure of the brain up to his time, and an extensive

comparison with the brains of other animals, although he did not carry his studies beyond what is visible to the unaided eye.

During the Reign of Terror in Paris, Georges Cuvier had the opportunity, as tutor to the son of a count, to spend half a dozen years at the seashore with plenty of time for study and reflection, and with no books to tell him what to think. Here he accumulated a remarkable amount of first-hand knowledge of many animals lower in the scale of life than fishes. Later he undertook to learn at first hand the structure of representatives of "all the groups of animals." He began with the lower forms, and his thoroughgoing study gave him a more comprehensive view of the different orders than anybody before him had attained. As an outcome of many years of such study he concluded that animal life had been created according to four distinct plans or types. These were (1) the vertebrates; (2) the molluscs, or soft-bodied animals; (3) the articulates or animals with jointed bodies; and (4) the radiates, animals with parts arranged around a center, like the sea-stars and jellyfish.

Cuvier, who opposed to the end of his days the idea of change in species, established the science of comparative anatomy, and thus helped his successors to see more clearly that evolution had in fact taken place. His was a great improvement upon earlier schemes of classification, although it still left a great deal for later students to supply. His view of types, with subsequent expansions, enables us to take a survey of the animal world without becoming hopelessly lost in the maze.

The Simplest Animals

We have seen (page 55) that our common notion of being "alive" includes certain activities and characteristics. Living things grow by assimilation, they are sensitive to external changes, they move, they throw off refuse, they breathe, they reproduce, and so on. It is not necessary, however, in

order to be alive, that a plant or an animal have the special organs with which we are familiar in ourselves. The simplest plants and animals have indeed no such special organs.

The simplest animals which we know consist of minute, shapeless lumps of what looks (under the microscope) like colorless jelly, or very fine froth (Fig. 16). Animals of this type live in water (or perhaps in the fluids of the body of some larger animal), and are found in all parts of the world. The ameba moves by protruding the jelly-like mass in one or in several directions, and then flowing into one of the protrusions. When it comes in contact with a solid particle, as a grain of sand, it withdraws this "false foot" and flows off to one side or the other. When it comes in contact with a solid particle that may serve as food, the jelly mass moves forward and envelops the object. Inside the body of the ameba this particle appears to be *digested* — that is, changed into chemical combinations that can be utilized by the living matter. The solid, undigested remains are removed by reversing the process of swallowing — that is, the ameba flows away from the refuse. The surface of the ameba absorbs oxygen from the surrounding water, and after portions of the material in the jelly are oxidized or "burned," the products of combustion are discharged by diffusing through to the outside.

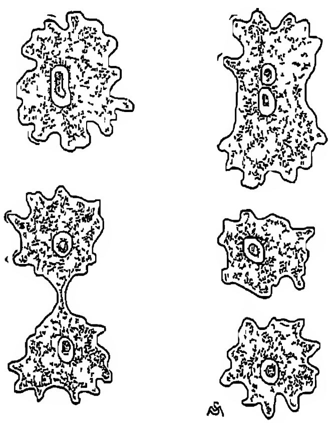


FIG. 16. THE ONE-CELLED ANIMAL, AMEBA

When this shapeless mass of jelly-like protoplasm attains its full size the *nucleus* or kernel lengthens out and gradually divides into two parts The rest of the animal's body also elongates and the two ends seem to move slowly away from each other until there are two distinct individuals Each of these is as complete as the other, and both are the same as the mother cell, except for size. From Gruenberg, Biology and Human Life, published by Ginn & Company

It may be easily shown that the ameba is influenced by contact, by light, by heat, by electric shock, and by chemical shock. In response to a stimulation the shapeless jelly-like

lump withdraws from the point of disturbance, or it rounds up into a nearly spherical mass. Chemical changes of various kinds go on internally, some continuously and others in response to changed conditions.

The ameba is typical, in its way of life, of thousands of animal species in which the individual's body is not subdivided into "cells." Some of these live in fresh water, some in salt water. Some are parasitic in the intestines or blood or other parts of higher animals; and some are parasitic upon plants. In some groups of these so-called one-celled animals the protoplasm or living substance protrudes as fine vibrat-

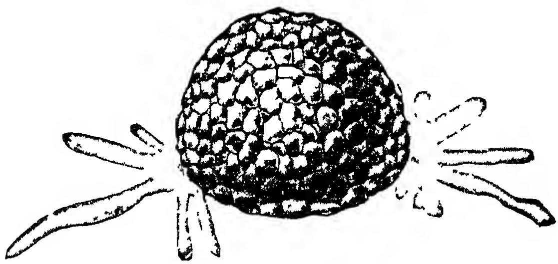


FIG. 17. DIFFLUGIA

This microscopic animal is representative of a large group in which the individual is like an ameba that builds a shell out of tiny sand particles

ing threads or lashes, by means of which the animal moves through the water. In some species a delicate armor is constructed of sand particles (Fig. 17). In some species reproduction takes place by a true sexual process, whereby two special structures (or entire individuals) unite as in fertilization to give rise to a new individual. In some species there are formed special non-sexual reproductive cells or spores. The parasite which is the cause of malaria is a relative of ameba that reproduces by both methods.

The Simplest Plants

Among the plants as well as among the animals the simplest forms consist of individuals that are not made up

of numerous cells. The bacteria, of which everybody has heard, show hardly any structure at all. The protoplasm is contained within a membrane or cell-wall. In some species delicate vibratile "hairs" project beyond the wall and serve as a means of locomotion. The individual absorbs water from the outside through its wall membrane, and discharges wastes in reverse direction in the same way. Most bacteria live in a fluid medium. In the presence of abundant moisture some bacteria secrete a ferment which can digest solid food material, and then absorb the fluid containing the digested food. While many bacteria are known to be parasitic and to cause disease in man and in other animals, most of them live upon dead organic matter and cause fermentation or decay. Indeed, they constitute an important link in the cycle of life, since they are responsible for converting most of the dead plant and animal bodies into food which succeeding generations utilize. We say to the dead, "Dust thou art, to dust returneth," but we do not always realize that it is the activity of bacteria that makes possible the return. The souring of milk, the curing of hay, the retting of flax, the spoiling of food are also parts of this general process of bacteria keeping themselves alive.

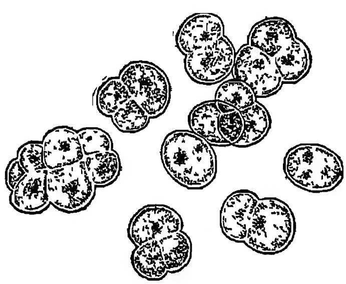


FIG 18 GREENSLIME

The pleurococcus consists of a single cell, a unit of protoplasm with a definite wall All the income is absorbed through the wall, in a fluid or gaseous state The by-products of metabolism are discharged by diffusion through the wall There are no special organs for taking in or for excreting When a cell divides into two, the daughter-cell may become separated or they may cling together From Gruenberg, Biology and Human Life, published by Ginn & Company

The greenslime found on the bark of trees and on the shingles of old houses (sometimes erroneously called "moss") represents another large group of one-celled plants (Fig. 18). Here, as in the bacteria, the individual consists of a single unit of protoplasm surrounded by a cell-wall. In

each cell is found some of the green substance (chlorophyl or leaf-green) characteristic of our common green plants. This is known to be an essential factor in the making of starch from water and carbon dioxid. The process of starch-making goes on only in the presence of light. From the starch, in the presence of other raw material absorbed with water from the dust on its resting place, the greenslime makes other food material. The food material is converted by the protoplasm into more protoplasm, resulting in the growth of the cell.

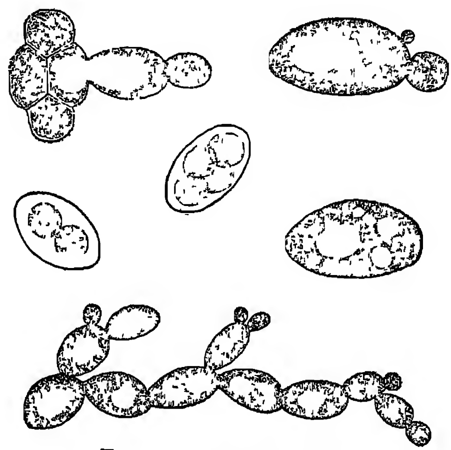


Fig 19 Yeast Plant

The cells of this plant multiply by pushing out buds Under certain conditions the protoplasm of a cell divides into two and then four parts, which then can remain inactive for an indefinite time These resting cells are called *spores* From Gruenberg, Elementary Biology, published by Ginn & Company

After reaching a certain size the single greenslime cell, or the single bacterium, divides, like an ameba, into two cells. Each new cell is a complete individual, differing from the mother-cell only in size. In other one-celled plants, like the common baker's or brewer's yeast (Fig. 19), the growing cell puts forth little extensions or "buds," which in turn continue to absorb nourishment from the surrounding fluid, and to grow. This budding appears to be a specialized mode of cell-division, for if a bud falls off it may continue to grow like an independent cell.

The Completeness of Lowest Forms

We call these very simple plants and animals "lower"; and we think of birds and sunflowers as "higher." Yet the lowest living things appear to be as well adapted to living

as are the highest. The ameba, for example, although it has no mouth, is able to take into itself what it needs in the way of food. Although it has no stomach, it is able to digest what it takes in as effectively for its needs as does a fish or a pig. Although it has neither lungs nor gills, it manages to get from its surroundings the oxygen it needs and to discharge, without any special breathing organs, the waste products of combustion. Although it has no muscles or limbs, no tail or fins, it can both swim and crawl. Without sense organs or nerves or brain it manages somehow to find what it needs and to escape injury — at least sufficiently to preserve the species from extermination. Although it has no special organs of reproduction it manages to leave offspring, notwithstanding that the individual, in reproducing, destroys his own identity.

The simplest plants likewise show adequate adaptation to the conditions under which they live, without any of the special organs that characterize higher forms. Some plants apparently can live without roots, stems or leaves, just as some animals can live without stomachs and livers and lungs.

Function Precedes Structure

From a study of the simplest plants and animals now living we come to realize that the essential functions of living things can be carried on in the absence of the special structures or organs which we have come to associate with those functions. To say that "function precedes structure" is merely to describe the facts, so far as they can be observed in any of the higher individuals that have special organs. The developing embryo digests food long before it has a stomach. It absorbs oxygen, utilizes it, and discharges carbon dioxid and other oxids, long before it has anything corresponding to a lung or a gill. It contracts in one part or another before there are any "muscles." It is sensitive to changes in external conditions before it elaborates nerves or sensory organs. Similarly we find that the "lowest" or

most primitive living things carry on the same essential functions as the " highest " or most complex and elaborate — the special organs characteristic of the latter being entirely lacking in the former. To show that function precedes structure in the history of life upon the earth, we should have to show that as a matter of chronology the simplest plants and animals made their appearance before the more complex ones. This has already been discussed in connection with the records disclosed by the fossil-bearing rocks (page 48).

To many the statement that function precedes structure will seem like saying that there was cutting before there were knives, or that there was killing before there were weapons. No matter how crude a tool or a weapon the savage of the early stone age fashioned out of a random stone, the instrument is there in advance of its operation. In the same way, the ameba does in fact carry on its functions by means of existing structural mechanisms, which we may, if we wish, properly consider as organs. Nevertheless, the distinction is important if we are to understand the evolutionary implications of the facts. The lowest stage shows us a body of seemingly undifferentiated protoplasm performing each and every function of living. From similar protoplasm we later see emerge specialized structures that seem almost to have lost the common characteristics of bare " protoplasm."

It may be helpful to reflect that in the history of human culture clothing was made before there were any tailors, food was cooked before there were any cooks, shelters were constructed long before there were architects, builders or contractors.

Division of Labor

In fresh-water ponds and in the ocean are found tiny animals that appear to be hardly more than hollow sacks (Fig. 20). The cells of the inner layer, chiefly food-preparers, are protected by those of the outer layer. Some of the external and some of the inner layer cells have extensions

at their bases, which spread between the two layers and are highly contractile: they may be considered primitive muscles. Other cells of the outer layer and a small number of the inner layer project slightly beyond the surface and are especially sensitive to disturbances: they may be considered as primitive nerve or sensory cells.

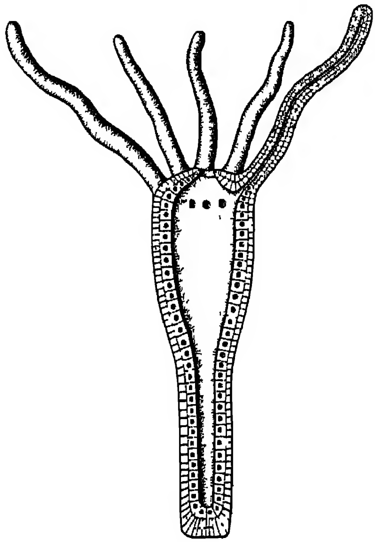


FIG. 20. THE HYDRA

This animal consists of two layers of cells The base of the sac is usually attached to some support, such as a stone or a bit of some plant At the open end are several hollow extensions or tentacles, which wave about in all directions The "mouth" receives food particles, which may be digested in the cavity The food prepared in the central cavity is made available to all the cells

We may note that in the hydra as in the ameba each cell assimilates food and grows, each cell is more or less irritable, more or less contractile. Moreover, each cell of the hydra is capable of dividing into two cells, as is the ameba; and the growth of the body results from the increase in the number of cells as well as from the enlargement of the individual cells. On the other hand, hydra shows what has been called a division of labor. Some cells carry on certain functions almost exclusively, or to a greater extent than some of the other cells. We may say there is a tendency for cells to specialize; and at the same time there is a certain interdependence among the different parts.

From General to Special

A comparison of all kinds of animals yields this general fact: we may arrange the various types to indicate a progressive increase in specialization, as from the one-celled animals

to the group represented by the hydra, from the hydra to several types of "worms," from worms to the jointed-legged animals like insects and spiders and lobsters, and so on to the backboned group. These facts do not of course tell us that there has been any genetic connection between the simpler and the more complex types, although they are in harmony with the supposition that there has been transformation of species.

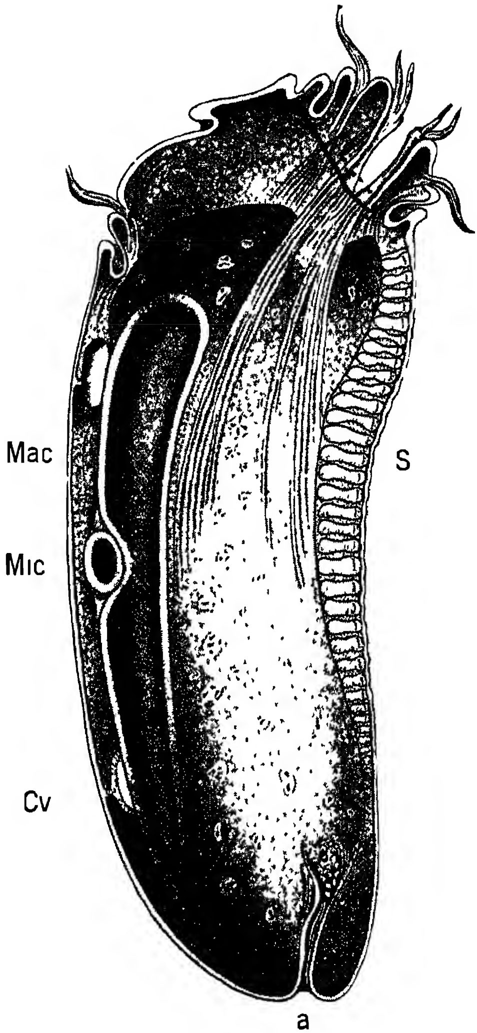


FIG. 21. DIPLODINIUM ECAUDATUM

This one-celled animal lives in the stomach of cattle In addition to the long macronucleus (Mac), the small micronucleus (Mic), and the contractile vacuole (Cv) commonly found in protozoa, this animal has a distinct anus (a), a skeletal support (S), an œsophagus, sensory tracts, motor bundles, and other structures corresponding to special organs or tissues of highly complex animals. Adapted from R. G. Sharp.

A division of labor, in the sense in which this expression is applied to living things, is to be expected only after there has been a certain amount of integrating or bringing together of units, and is therefore more pronounced in larger organisms than in the microscopic forms. Nevertheless, even the one-celled animals, among their thousands

of species, show numerous examples of extreme specialization (Fig. 21). Plants also present to us graded series from the simplest types, in which each cell does everything that pertains to being alive, to the complex ferns and seed plants, in which there are many kinds of organs and many kinds of tissues adapted to the various vital processes and to specialized conditions of living. Finally, within each type, or even smaller subdivision, it is possible to find gradations of organization from the more general to the more specialized. These facts point to evolution where we can apply to them the test of *order in time*. As we saw (page 35), the more generalized forms of any series appear in older rocks, the more specialized forms appear in more recent rocks.

Homology

Within the group of animals that belong to the same type or plan of structure there is a remarkable adherence to the pattern, even where the conditions of life are radically different, and where a direct adaptation of organs to particular needs would seem to be called for — if we assume for each species a special act of creation. This is illustrated by the facts assembled under the so-called principle of *homology*. An extreme example of homologous organs that behave differently in two different species is furnished by contrasting a mammal like the whale, which lives in the water, and a mammal like the cat, which lives on land. The striking difference in outward appearance, in the form of the limbs, in the habits of locomotion and feeding, and in hundreds of other details go hand in hand with equally numerous similarities in details of structure.

Arms and Legs

There are five distinct classes of backboned animals, besides a number of *species* that are not so easily classified. These five principal classes are the fishes, the amphibians

(which include frogs, toads, newts, salamanders), the reptiles, the birds, and the mammals. In the body of each of these animals there is an internal skeleton or framework consisting of a series of separate bones or vertebræ, forming the "backbone" and carrying the brain box at one end, and, typically, two pairs of appendages or limbs corresponding to our arms and legs.

The correspondence between our legs and the hind legs of four-legged beasts is obvious. The correspondence between our arms and the wings of birds has also been commonly observed. Many people fail to see a similar correspondence between the four limbs of quadrupeds or birds and the two pairs of fins in fishes. For one thing, most of the common fishes have several unpaired fins in addition to the two pairs, so that the number of outgrowths is not typically four. For another thing, the fins themselves do not in their appearance suggest arms or legs outwardly, so that there is no suggestion of correspondence in their structure. There are also numerous backboned animals that do not have four limbs. The whale, for example, has only one pair of flippers, and as everybody can see for himself, snakes have no limbs at all.

When we examine the arms and legs more closely, and especially the skeletal parts, which have distinct structures that can be most easily preserved, measured, and compared, we discover some peculiar relationship (Fig. 22). In the first place, arms and legs are found to be constructed on pretty much the same plan. This correspondence between the hind leg and the front leg in backboned animals is followed, in the second place, by what is perhaps a more striking correspondence between the limbs of one class of vertebrates and those of other classes (Fig. 23). The legs of a horse and a crocodile, the legs of a salamander and an eagle show fundamentally the same plan of structure. There is nothing in the mode of life or in the outward appearance that would lead us to expect such remarkably close correspondence. We might indeed say that the leg is a leg, and be

satisfied with the similarities which we find on the ground that after all there is an ideal pattern for legs. If, however, we go further and compare the front leg of the crocodile

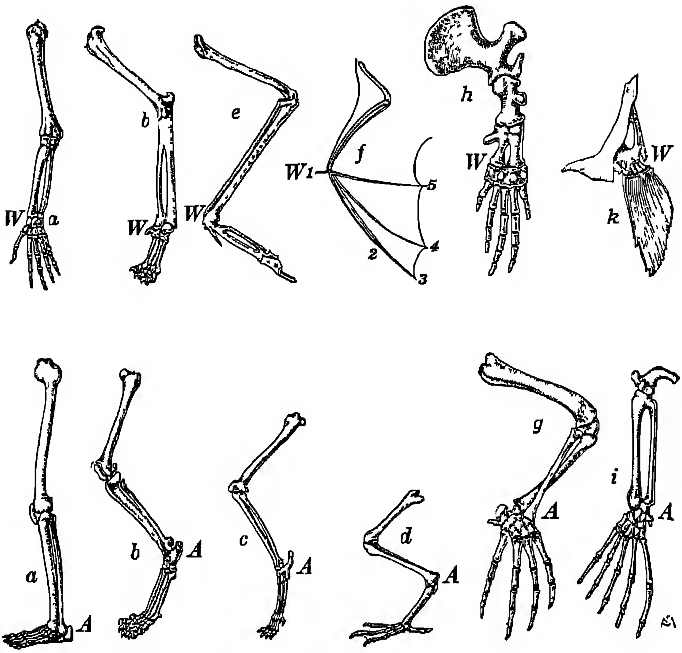


FIG. 22 HOMOLOGIES BETWEEN THE FRONT LIMBS AND THE HIND LIMBS OF VERTEBRATES

There is a long section between the joint connecting the limb with the shoulder or the hip girdle, and the next joint, which corresponds to the knee or elbow. This is followed by a section in which there are two bones lying side by side Then there are several small bones that make up the ankle (*A*) or the wrist (*W*) Finally there are the bones that make up the hand or foot proper, ending typically in five rows, constituting the skeleton of the fingers or toes. Upper row, front limbs, lower row, hind limbs *a*, man, *b*, lion, *c*, wolf, *d*, duck, *e*, vulture, *f*, bat, g, crocodile, *h*, whale, *i*, seal; *k*, halibut From Gruenberg, Biology and Human Life, published by Ginn & Company.

with the wing of the eagle, the front leg of the horse with the wing of the bat, or the front leg of the cat with the flipper of the whale, we shall find remarkable similarities in spite of the most diverse outward appearance, and in spite

of the obvious differences in the functions or uses of these organs. It would be entirely too far-fetched to say that the flipper of a whale is constructed on the same plan as the arm of a man because either represents an ideal pattern for the arm.

Bone for bone, there is homology between front limbs

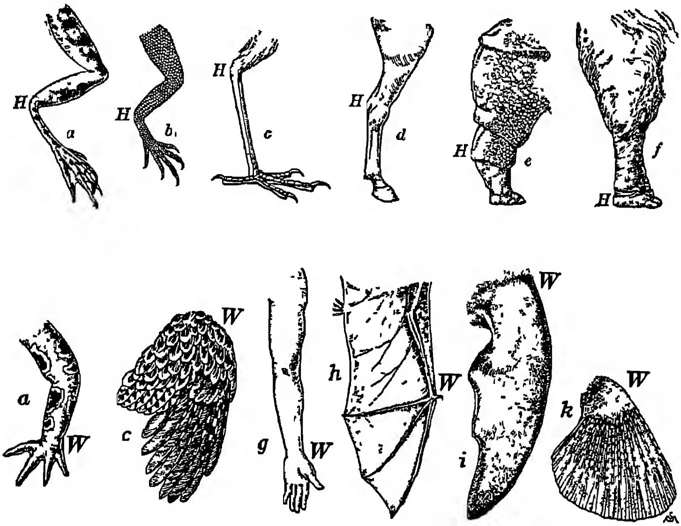


FIG. 23. HOMOLOGIES AMONG THE LIMBS OF THE DIFFERENT CLASSES OF VERTEBRATES

Walking, crawling, swimming, flying — all the various modes of locomotion found among the five classes of backboned animals — are carried on by variations of the same fundamental structures Hind limbs in upper row, with varying positions of the heel, *H*, fore limbs in lower row, with varying positions of the wrist, *W* *a*, frog, *b*, lizard, *c*, bird, *d*, horse; *e*, hippopotamus, *f*, elephant, *g*, man, *h*, bat, *i*, dolphin, *k*, blackfish From Gruenberg, Biology and Human Life, published by Ginn & Company

and hind limbs. Excepting the fins of fishes, which are not so highly specialized, the limbs of one class of backboned animals corresponds to the limbs of other classes of backboned animals, whether they live on land or in the water, in the air or in caves or underground.

Similar correspondence in detail, in apparent defiance of diverse modes of living, extends among the vertebrates to

the brain and the nervous system and the special sense organs, to the digestive system and to the muscles. It extends even to the reproductive organs, although the fishes generally lay their eggs in the water and abandon them, the reptiles and birds lay eggs and make more or less provision for the young, and mammals carry the embryo to a relatively advanced stage and then suckle the young. The neck of the giraffe has the same number of vertebræ as the neck of the mouse; the leg of the stork repeats bone for bone the leg of the sparrow.

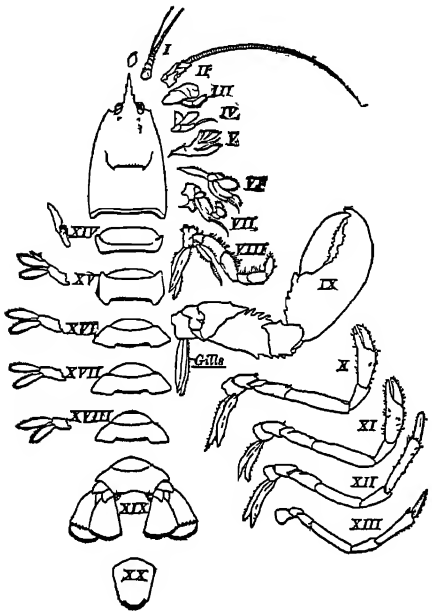


FIG. 24. HOMOLOGIES AMONG THE APPENDAGES OF THE LOBSTER

In the Crustacea all the appendages are built on the same plan, but each segment of the body (represented by Roman numerals) may have a pair of distinctive organs. *I* and *II* are sensory; *III–V* combine sensory functions with food-getting; *VI–VIII* are chiefly food-getters, but are also related to breathing, *IX* is the nipper; *X* and *XI* are both grasping and locomotor organs; *XII* and *XIII* are walking legs The abdominal appendages *XIV–XVIII* are called swimmerets and probably assist in slow swimming *XIV* and *XV* are also related to reproduction in the male, and in the female all the swimmerets carry the hatching eggs and larvæ *XIX* and *XX* spread out into a flat tail-paddle, used in swimming backward suddenly. From Gruenberg, Biology and Human Life, published by Ginn & Company.

Jaws and Claws

The arthropoda, which show a very remarkable degree of specialization among the higher members of the group, also yield an impressive array of variations upon identical themes. Among the lobsters and crayfish (Decapods) the abdomen is seen to be segmented, like the body of a grasshopper or wasp. Each segment carries a pair of append-

ages. The head and thorax are fused together, in contrast to the distinct head and thorax of insects (Fig. 24). Close examination, however, reveals a faint suggestion of segmentation in the thorax, with a pair of appendages corresponding to each segment. It is impossible to find distinct segments in the head region, but the series of appendages is continued in the form of various mouth-parts or "food graspers," convenient substitutes for forks and spoons and pushers. If we examine one of the abdominal legs, we find that each consists of a basal joint with two branches. The number of joints on one of the walking legs is easily counted: and the same number appears on each of the others, including the large nippers. The organs about the mouth, including the "jaws," which work from side to side, and the "lips" are all modifications of the same "leg" pattern. In some of these mouth-legs, the outer branches are sensory; in others they push food into the mouth; and in still others they maintain the current of water which supplies the gills with fresh oxygen and carries away the carbon dioxid. The abdominal legs assist somewhat in swimming, but in the male one pair is modified as an organ for transferring the sperms.

Among the insects, which show perhaps the greatest range of specialization found in any class of animals, the different orders have different kinds of mouths, adapted to different feeding habits (Fig. 25). Yet in every case the fundamental plan is exactly the same, and traceable in detail to the corresponding parts of less specialized arthropods, and to a primitive "leg" pattern.

Homology in Plants

In plants as well as in animals we find that fundamentally identical structures are applied to a great variety of functions. In the grape a leaf is "modified" into a climbing organ, or tendril. In the black locust, a pair of stipules, which are leaflike in roses and willows, appear as sharp thorns. In the flowers of the vast array of seed-bearing plants,

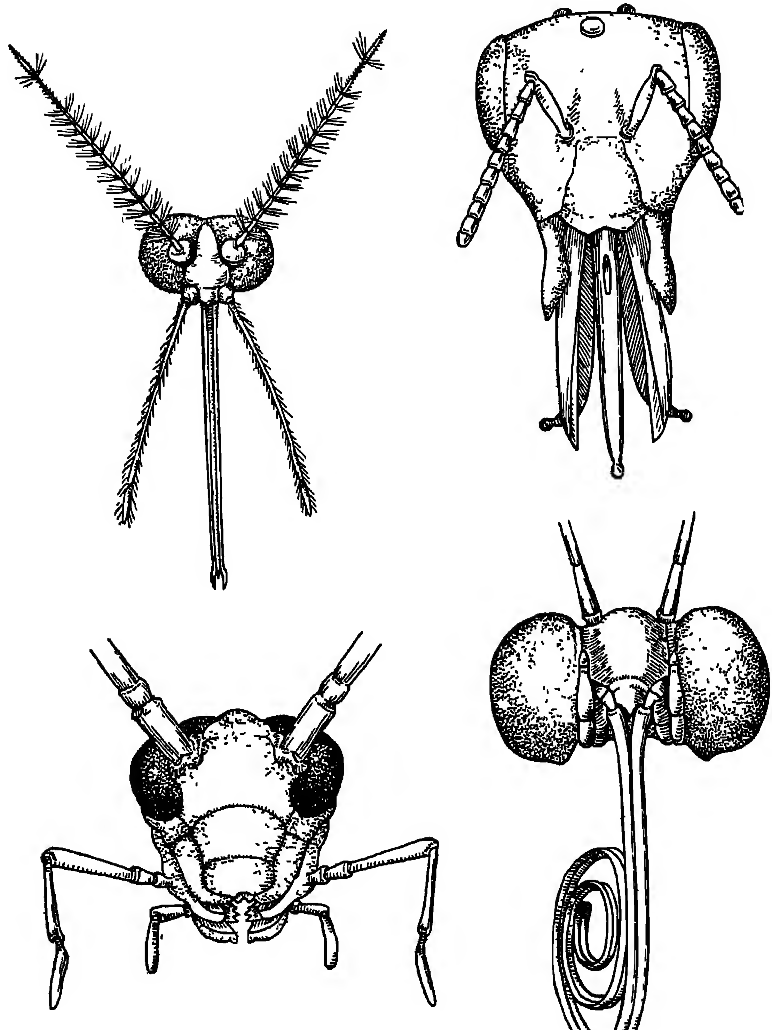


FIG. 25 MOUTHS OF INSECTS

The stinging or piercing mouth of the mosquito, the combination sucking and cutting mouth of the bee, the biting mouth of the grasshopper, and the long, delicate proboscis of a butterfly, each with its specialized feelers and pushers, represent a great variety of structures built on fundamentally the same plan.

" leaves " masquerade as spathes, as involucre scales or bracts, as sepals, as petals, as stamens, as carpels. They thus furnish the burr of a nut or the flesh of an apple and the pod of a bean. The pitcher of the pitcher plant, the trap of the Venus's flytrap or of the sundew, a layer of onion, all these are " leaves." The flower of the common water lily shows the gradation from sepal, through petal and stamen to carpel (Fig. 26).

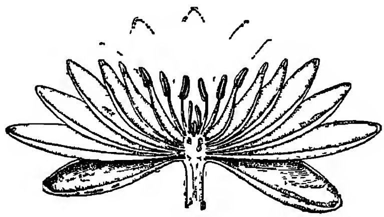


FIG. 26. HOMOLOGY IN THE STRUCTURE OF A FLOWER

As we pass toward the center of the flower of the water lily the structures of each circle become less and less like " leaves," and more and more narrow, until they are definitely stamens, made up of the stalklike filament and the distinct anther From Gruenberg, Biology and Human Life, published by Ginn & Company

Unity of Life

The great variety of appearance and function assumed by fundamentally identical structures may be explained by considering them adaptations to different modes and conditions of life. We may say, if we like, that the limb of a whale differs from that of a camel or of a bird because it has to serve its owner in a different way. The lobster with a whole series of " legs " uses the ones on the head for certain purposes and those on the abdomen for other purposes. There still remains, however, the question of remoter relationship. How does it come about that different classes of backboned animals have the same fundamental structures to begin with? We can understand that a plant can put forth leaves and have a great variety of " leaves " serving a variety of functions. They are all parts of the same organism and contribute to the life of the whole; there is a division of labor among structures that are specialized as the plant develops. In a similar manner we might understand that the lobster and other arthropods can produce outgrowths or appendages which become differentiated or specialized in the course of development. It is not so easy to understand the funda-

mental identity of wings and legs and arms and flippers unless here too there is a far-reaching kinship, or common origin.

The assumption that kinship is somehow indicated by similarity must be applied here among the different classes of backboned animals, among the different classes of arthropods, among the different classes of any main branch of the animal world, just as we apply it to different breeds of dogs or pigeons. We cannot escape the conclusion that there is likeness because there is descent from a common ancestry.

Correlation

We have seen that there is a unity in all life in the sense that all living things carry on the same fundamental processes. This means that, on the whole, a plant or animal remains alive as long as it maintains a certain balance between internal processes and external conditions. There must be an income of materials. There must be an internal redistribution of materials. There must be a transformation of materials and a rejection or excretion of certain portions. There must be escape from enemies as well as from unfavorable conditions of moisture, temperature, light or darkness, and so on. Living things are adapted to the conditions in which they live — they must be, or they could not continue to live. The great variety of life corresponds to the great variety of conditions — and the living beings themselves make up an important part of the effective environment for one another. In all the variety there remains the common factor called "protoplasm," a complex mixture of numerous substances — and the common processes. All life is one in essential performance and needs, regardless of how it originated.

The necessity of maintaining certain relationships to the outer world — the physical conditions, the food supply, possible enemies — brings about a unity in the organism that Cuvier emphasized in his doctrine of correlation. A mode of life involves all the factors of the environment and

all the activities. The structure of an animal is therefore adjusted to its particular mode of life in all of its parts. A bird of prey, for example, differs from a seed-eating ground bird in every detail of structure. Not only the claws and the beak, but the eye and the viscera, the skeleton and the muscles are characteristic for its mode of life. It was on this doctrine of correlation that Cuvier thought he could recognize an animal from almost any sample taken from its body. And indeed he did do remarkably well in reconstructing fossil animals from mere fragments, for there is a kernel of sound truth in this principle, although most comparative anatomists since Cuvier's time do not attach to it as much weight as he did.

There is, however, another sense in which all life is one. That is the fact that we are unable to locate " life " in any particular part of the plant or animal body, but find that being alive is a condition of the organism as a whole. It is true that portions of an animal can be removed without killing the individual, and that portions themselves may be maintained as growing pieces of tissue. Dr. Alexis Carrel of the Rockefeller Institute has maintained fragments of chicken tissue " alive " for over fifteen years. It is the whole organism, however, that can maintain itself and reproduce itself, and the parts have meaning only in relation to the organism as a unity.

Recognizing then that all living things have so much in common and that the organism characteristically maintains itself as a unity toward the outside world, it becomes difficult to reconcile observed facts with the idea that each species was especially created for the place in the world in which we find it, and that its various parts and activities were supplied it from the first to suit its needs.

Superfluous Structures

When we compared the different classes of vertebrate animals emphasis was placed on the unity of structure run-

ning throughout the series, notwithstanding the wide range of living conditions to which the various forms are adapted The wing of the bird, we saw, is built on the same pattern as the leg of the elephant and the flipper of the whale, or the wing of the bat. The limbs of mammals are built on the same pattern as the limbs of reptiles and amphibians as well as of birds. Now we may go further and find that the Greenland whale has, in addition to the flipper with an arm-like framework, a set of bones corresponding to the hind leg, which never appear at the surface (Fig. 27).

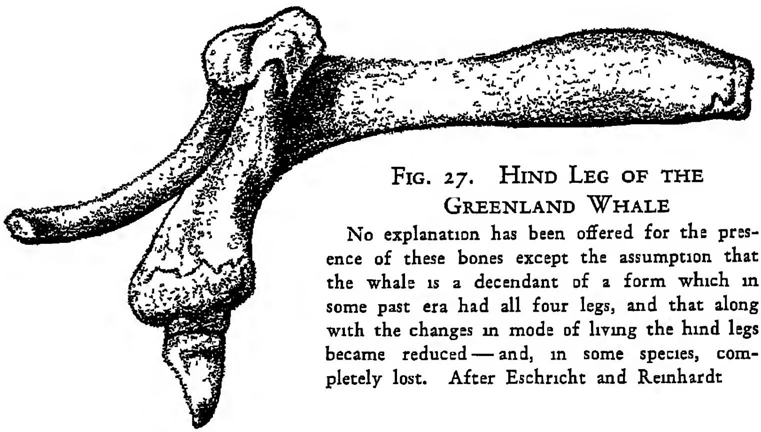


FIG. 27. HIND LEG OF THE GREENLAND WHALE

No explanation has been offered for the presence of these bones except the assumption that the whale is a decendant of a form which in some past era had all four legs, and that along with the changes in mode of living the hind legs became reduced — and, in some species, completely lost. After Eschricht and Reinhardt

The relationship of snakes to lizards, alligators and turtles has been deduced from the many resemblances in structural details and in development, notwithstanding the absence of legs in snakes and their uniform presence in the other "reptiles." Yet the python retains a vestige inherited from a hypothetical ancestor with paired legs, in the form of two horny hooks connected with a short chain of reduced bones that correspond to the hip girdle in other reptiles. Many similar relics are found in the early stages of development (Fig. 28).

We need not look through rare museum specimens for evidences of kinship among animals of different orders or classes. Every modern animal is a living museum of such

relics. There are men — and women, too — who can move their ears, although the accomplishment is not considered of great moment in cultured circles. The three muscles on each side that make this movement possible are identical in detail with muscles found in other mammals, and used by these other animals with greater assurance and to better purpose. We cannot account for these muscles if we assume

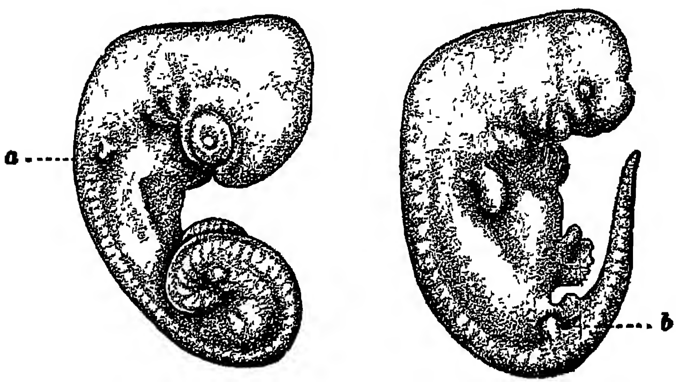


FIG. 28 SOME CURIOUS BUT USELESS RELICS

In the glass snake, a kind of lizard (*Anguis fragilis*), the buds of the front legs are present during an early stage of development, *a*, but the fully formed animal is footless In the porpoise (*Phocæna communis*) the buds of the hind legs or flippers are present during an early stage of development, *b*, but the fully developed animal has only the front flippers From Gruenberg, Biology and Human Life, published by Ginn & Company.

that the structure as a whole was designed for man's use. We can account for them if we assume that the structure is the result of ages of modification of an ancient heritage.

Blind Alleys

More familiar to most of us is the famous vermiform appendix, which the general public discovered a generation ago as the seat of fashionable illness. This appendix (Fig. 29) is a blind sac near the beginning of the large intestine. It corresponds in structure and location to a part of the in-

testine which is relatively larger in many of the herbivorous animals and in the orang-outang than it is in man. In other mammals, however, it is completely reduced. In the unborn infant the appendix is relatively larger than it is later in life. Unless we assume that this organ relates its possessor to other

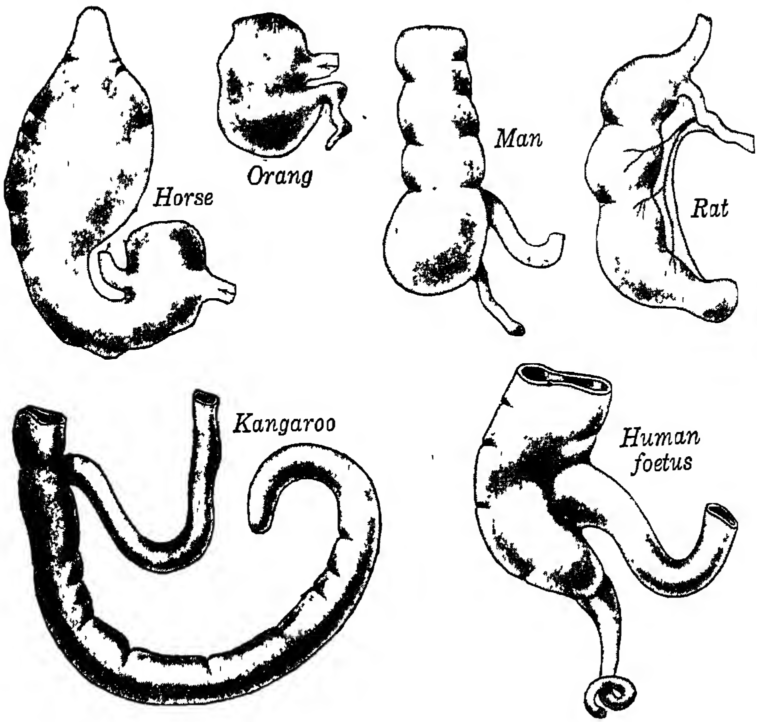


FIG. 29. THE VERMIFORM APPENDIX

This blind sac near the beginning of the large intestine seems to be an organ of diminishing magnitude, as we may judge from its relative size among the members of different families of mammals, and from its relative size in the different stages of individual development

forms which also have it, we must seek its meaning in some other theory of the origin of species. To assume that the orang-outang was created with a definite purpose must force us to find a related purpose in the presence of this structure. It has been abundantly demonstrated that the vermiform appendix is not only a useless structure but also, and perhaps

because of its very uselessness, a source of danger to the organism. The assumption of special creation might imply that this blind sac was put into man and into other animals

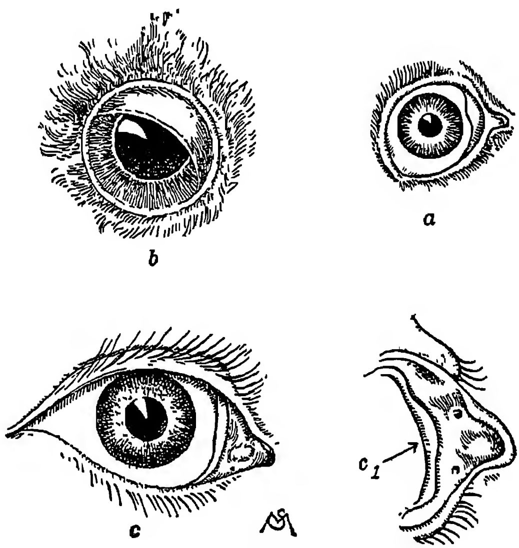


FIG. 30. THE THIRD EYELID

The little fold of tissue extending from the inner corner of the eye has been called the "third eyelid," although there is nothing about it to suggest an eyelid, in most of the familiar animals. In birds and in certain reptiles and amphibians this membrane can be drawn over the eye so as to cover it completely, but among primates it is reduced to a negligible wrinkle of skin. *a*, eye of ape; *b*, eye of owl, *c*, human eye; c_1 the semi-lunar fold, eye-ball removed. From Gruenberg, Biology and Human Life, published by Ginn & Company

simply as a means of misleading him in his efforts to understand the world in which he lives.

Another useless structure which finds its readiest explanation in the supposition that there is a basic kinship among various orders of life is the semi-lunar fold (Fig. 30). Here again the obvious "fitness" of the structure in some groups of animals and its obvious superfluity in other groups challenges us to explain its presence on some the-

ory other than the supposition that an inscrutable intelligence placed it in our bodies for the purpose of blinding us. While it cleans the eyeball and shuts out light in the lower classes of vertebrates, it does not interfere with vision. Unless we deliberately shut our eyes, we can see past this and hope to understand.

Robert Wiedersheim, a German professor of human anatomy, found nearly two hundred structures that have no relation at all to the life or effectiveness of the organism but that correspond to structures occurring in a functional state in other animals, especially primates. It must be admitted that in many cases the student will report "no function" when he is warranted only in saying "I can find no function." There are indeed numerous structures in the human body having very significant functions that have come to be recognized, as a result of animal experimentation and clinical studies, only within a generation. Among these is the pineal gland lying between the two halves of the brain near the optic lobes. This structure is smaller in the adult than it is in the embryo, and is larger in some other mammals than it is in man. It is not, however, a rudimentary or vestigial structure, in the sense in which this term has been used by biologists, regardless of its history in the various classes of backboned animals, since it has in the human race a well defined function. In the same way an earlier generation of scientists speculated regarding the origin and meaning of the pituitary gland and the thymus, whereas today we are finding out a great deal about these structures in terms of their relations to the growth and development of the body. It is nevertheless true that there remain structures whose homologies are perfectly clear and whose presence in one or another group of plants or animals cannot, on any theory of clear-cut purposeful creation, be accounted for.

Reduced Organs

Other animals also carry these vestiges about for whatever they may mean. Insects that live on ocean islands are

in danger of being blown away by strong winds; wings are therefore of disadvantage to them. We find accordingly that most such insects cannot fly. Yet they are not only similar to the insects of neighboring continents in their general form and structure, but they all retain rudiments or vestiges of wings. The loggerhead duck of South America is unable to fly. Its wings are small and can only be flapped. Whatever value these wings may be to their possessor, they are obviously reduced wings and suggest that the ancestors of this bird in some remote past had functional wings. We cannot of course "prove" that the wings of the loggerhead duck have been reduced in this sense. We know, however, that they are reduced wings because the young of this species strangely enough have fully developed wings with which they can fly. Here the reduction takes place in the course of each individual's lifetime, as with the tail of the individual human being (see Fig. 52).

The skeleton of the horse's foot contains bones that have been described as corresponding to undeveloped toes. Again, as with any historical problem, we cannot "prove" that the ancestor of the horse had real toes corresponding to these bones (except as we infer, from the series of fossils, the past history of the tribe; see page 43). Nevertheless, we do find occasionally a colt that has two smaller toes behind the hoof — that is, these useless bones sometimes overdevelop and reveal their nature as toes. A similar condition is sometimes found in pigs and in other hoofed animals. Such outcroppings of latent characters are quite analogous to so-called "throw-backs" among domesticated animals and among human beings. We recognize a trait that was present in a remote ancestor of a person, but not in the immediate ancestors, and accept it as an indication of heredity or kinship because we happen to know the family history. We should be prepared to accept such appearances as indications of kinship where the family history is not accessible to us.

The blindness of cave animals has been long known. This is so much in keeping with our common assumption of fitness in the structure of living things that it has been ac-

cepted by most people without arousing any wonder. After all, what use can cave animals make of functional eyes? The interesting thing about this blindness is the fact that cave animals have reduced sightless eyes, although we might suppose that animals specially created for the darkness could logically be produced without eyes in the first place. Moreover, some of the blind crustaceans found in dark caves have the eye stalk like that in a crab; but the seeing part of the structure is absent. The presence of the eye stalk would need to be explained if we assume that the species was specially created for its particular abode and its particular mode of life. The presence of rudimentary structures is, however, quite in harmony with the assumption that these blind animals are descendants of animals that could see. Incidentally, it is interesting to note that although the blind cave animals in America are just as blind as those of Europe, they are different kinds of fish and crustaceans in the two continents. Cave animals aside from being blind are very much like the other animals of the corresponding region — not like cave animals in other parts of the world.

Analogies

In the fall every gust of wind carries multitudes of seeds from many different kinds of plants. Some of these seeds have flat expansions or leaflike attachments which are commonly spoken of as "wings." Not even a little child is deceived by this word into thinking that the seeds of the maple, for example, propel themselves through the air as do birds, by means of their "wings." These expanded structures are *wing-like* but they are not wings, and we say "wings" as a short cut, to avoid awkward speech like "thin spread-out portions that suggest the wings of birds." The resemblance between two different structures in such cases is sufficient to warrant the use of the same name, notwithstanding the many important differences between the objects.

Analogies

When we speak of the wings of a bat, the resemblances to the wings of a bird are more numerous. We see especially that in both animals the wings do actually serve for locomotion through the air, and that in both cases the wings propel the animal by flapping or fluttering against the air. In the same way the wings of a butterfly or of a mosquito do more than look like wings: they *act* like wings. We find throughout nature that organs which are quite different from each other in their structure may nevertheless act in the same way. The leg of a horse, for example, is a totally different kind of organ from the leg of a lobster, yet both are legs in the sense that they serve their owners in locomotion on a solid surface. That is to say, they both behave in the same way. The humming bird sips the nectar from the flower through its beak, and the butterfly sucks nectar through its "proboscis" — two entirely different kinds of structures do the same kind of work; and the proboscis or trunk of the elephant is a still different kind of organ.

People sometimes contrast the breathing among different kinds of organisms by saying that "the gills are the lungs of the fish," or even that "the leaves are the lungs of the tree." These statements are true only in the sense that gills and lungs and leaves are all alike in having some relation to breathing. It would be just as logical to say that our lungs are our gills, or that the lungs are our leaves. A little observation will show that while the many processes that go on in a living thing are repeated in the different orders of plants and animals, they are carried on by strikingly different organs. The fact that two or more structurally different kinds of organs may nevertheless carry on the same kind of function is spoken of as *analogy*. Two organs of different kinds of plants or in different kinds of animals that have similar functions are said to be *analogous*.

In so far as different kinds of plants or different kinds of animals are adapted to similar conditions, we are likely to find analogies among them. The eyes of insects and the eyes of backboned animals are radically different kinds of

organs in their development and in their structure, yet both make possible some kind of "seeing." The feelers of certain insects and our ears are so different in their development and so different in their structure that nobody could mistake one for the other. Yet both serve their owners in perceiving

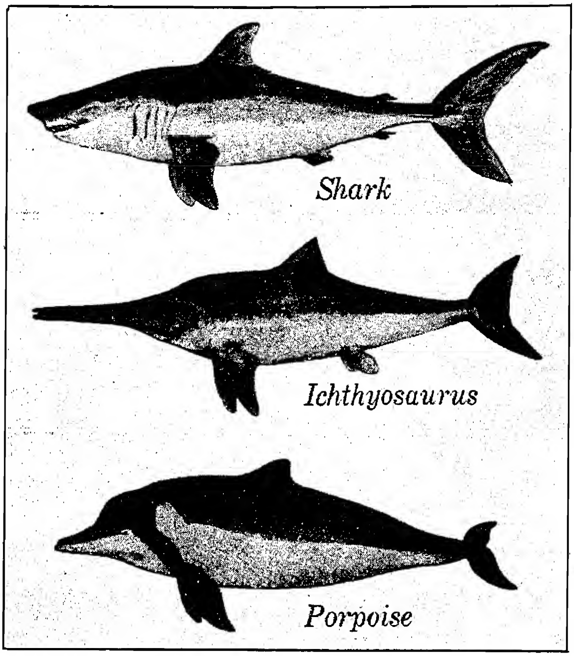


FIG. 31. CONVERGENT ADAPTATION OF FORM

The general form of an animal is frequently related to the conditions under which it lives rather than to more fundamental characteristics. The modern mammal, porpoise, and the ancient reptile, ichtyosaurus, have the outward form of a "fish." After Osborn.

"sound." The egg of a bird is totally unlike the seed of a radish, yet both are alike in the function of starting a new individual life. Analogies are to be found not only between one type of animal and another, but also between plants and animals. Since all living things have in common the necessity of meeting certain conditions in the environment, all of

us must somehow carry on certain common activities. The striking fact is that similar results, so far as concerns maintaining life, are obtained in so many different ways.

Convergence and Divergence

It has been pointed out that adaptations may be brought about in two different ways — if we disregard the theory of special creation.

1. Unrelated species, having to live under similar conditions, come to assume similarities. Thus the whale, a mam-

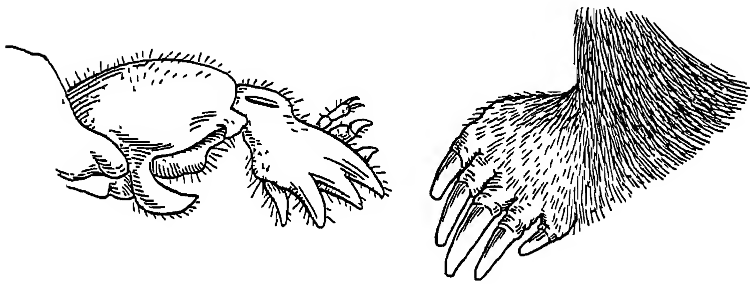


FIG. 32. DIGGERS FROM DIFFERENT SOURCES

The front legs of the mole cricket, an insect, and the front legs of the mole, a mammal, show striking superficial resemblances, and these are related to the similar ways in which the two animals use these structures

mal, the squid, a mollusc, the fossil ichtyosaur, a reptile, present an outward appearance suggesting a "fish"; there is here such an adaptation of form to conditions of living that animals of unrelated stocks resemble one another (Fig. 31). Insects belonging to distinct orders assume similarities of color or even of form — as certain katydids (orthoptera) and certain "bugs" (hemiptera) — because of their supposed protective advantage; and green snakes and green lizards are just as green as green katydids.

A remarkable instance is seen in the resemblance between the front feet of the mole, a ground-burrowing mammal, and the front legs of the mole cricket, an insect with somewhat similar habits (Fig. 32). Nobody giving attention

to these animals would suspect a "relationship" on the basis of the similarity between the digging feet of the two forms.

2. Related species, coming to live under different conditions, adapt themselves accordingly and so acquire diver-

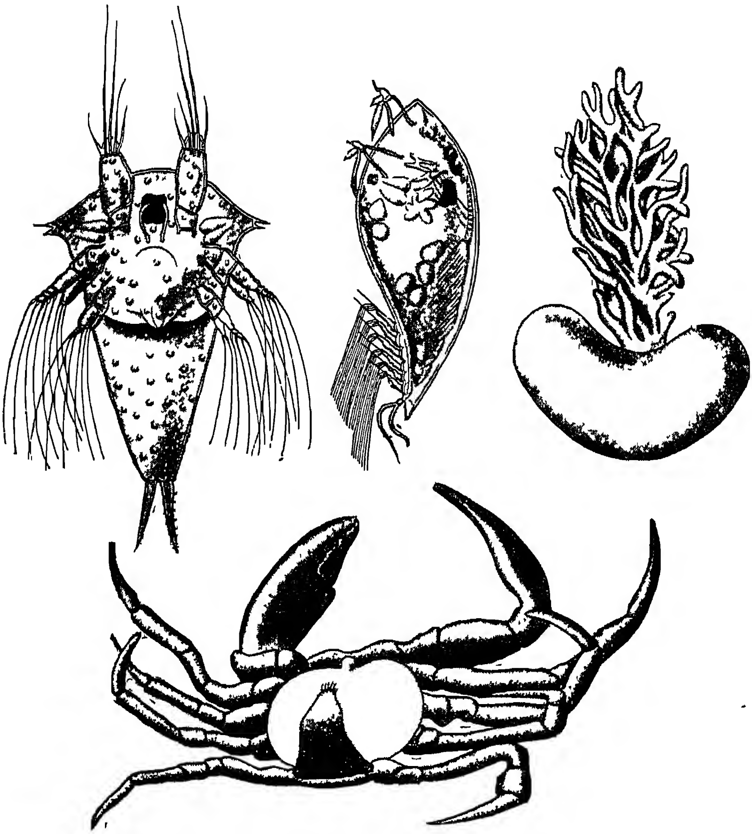


FIG. 33. DIVERGENT ADAPTATION

In the early stages of development all crabs look pretty much alike The crab *Carcinus* is shown lying on its back, with a parasite attached to the abdomen. This parasite is shown separately, above to the right, hardly more than a sac with branching suckers through which it absorbs its nutrition from the juices of the host. It is only by a study of the early stages of this parasite that we recognize it also to be a crab, *Sacculina*

gent forms and structures. A striking example is furnished by the parasitic crustacean, *Sacculina,* and its host the crab *Carcinus* (Fig. 33). The differences between the ordinary

cricket and the mole cricket may be taken to illustrate this idea, since the two forms are sufficiently alike to be recognized as of the same family by the casual observer, and yet show marked traits that are obviously related to habits of life.

The importance of this dynamic aspect of adaptation was long ago recognized in connection with problems of classification. Richard Owen, a comparative anatomist who extended Cuvier's work in many directions, found it necessary to make the distinction between organs and structures that were "really" the same, and those that only "seemed" to be alike. For this purpose he invented the terms *homologous* for the former and *analogous* for resemblances related to function. It was also a simpler matter to describe relative positions of organs than to find out exact facts about functions. There was a tendency to disregard analogies in systematic descriptions and the emphasis came to be laid upon the equivalence or homology of parts. Later, Ray Lankester developed the distinction still further since it is not always easy to apply Owen's tests. He accordingly proposed the terms *Homogeny* and *Homoplasy* to denote these two concepts: First, the similarities or identities due to *common origins;* and Second, the similarities or identities due to adaptation to *common functions* or living conditions.

President Henry Fairfield Osborn has unified thousands of cases from the systematists and field students into two general laws:

1. The law of adaptive convergence or parallelism of form, being the production of externally similar forms in adaptation to similar external natural forces.

2. The law of adaptive radiation or divergence, being the tendency of descendants of a primitive stock to develop differences of form while radiating into areas of unlike living conditions.

Without being able to say just how the adaptations, whether convergent or divergent, are brought about, the biologist can support these general statements with abun-

dant concrete examples. In recent years there have been added to the evidences of the observers increasing evidence from the experimental laboratory. It can be shown, for example, that the formation of the vertebrate eye proceeds from two distinct structural origins in the embryo. One of these produces the sensitive region or retina as a protrusion from the brain, forming the so-called optic vesicle. The other gives rise to the refracting apparatus or lens as an ingrowth from the skin. By removing the optic vesicle early in an animal's development, it is possible to prevent the formation of the uninjured skin area into a lens. The removal of the skin, however, does *not* interfere with the development of the optic vesicle, nor does the separation of the bud from the brain. If now such an optic vesicle be removed from a young salamander tadpole and engrafted under the skin in another part of the body, the skin overlying the vesicle will develop into a perfect lens. Or again, if the skin above the vesicle is removed and a bit of skin from another part of the body is grafted above the optic vesicle, the foreign skin will develop into a lens. Experiments pointing to the influence of physico-chemical factors upon development have revealed the plasticity of organisms and especially the inherent capacity for adaptive modification.

Analogies and Homologies

From the point of view of evolution, the interesting principle of analogy would not be significant taken by itself, since no matter how a given species came into existence, the individual plant or the individual animal can maintain itself only if it has structures through which it can carry on the functions essential to keeping alive. Taken in conjunction with the fact of homology, however, it is of first importance. Let fishes and lobsters breathe through gills; let the trees of the wood breathe through their leaves: but what should the air-breathing birds and mammals have to do with gills? Or why should herbs use their breathing leaves for catching

flies or for climbing trees? It seems eminently reasonable that the bones of birds should be light and hollow, that the air spaces in the bones should be connected with the lungs: the bird's mode of life demands lightness combined with strength. But what shall we say of similar air spaces in the bones, connected with the lungs — in the crocodile?

On the one hand is the persistence of type under all sorts of conditions. On the other hand is the adaptation of the same structures to the greatest variety of functions. From the point of view of special creation, we should expect not only a direct adaptation of a given species to its place in the world, but an equally direct adaptation of its organs to its special mode of life — *just what we do not find*. From the point of view of evolution, both the persistence of type and the marvelous plasticity and adaptability of identical structures can be understood as the normal result of descent with modifications.

Ingenuity versus Resourcefulness

Romanes, in his *Darwin and after Darwin*, stresses the variety of functions to which a particular structure is adapted in different organisms, and the various structures which are adapted to the same function:

> "On the one hand, we meet with structures which are perfectly homologous and yet in no way analogous: the structural elements remain, but are profoundly modified so as to perform wholly different functions. On the other hand, we meet with structures which are perfectly analogous, and yet in no way homologous; totally different structures are modified to perform the same functions. How then are we to explain these things? By design manifested in special creation, or by descent with adaptive modification? If it is said by design manifested in special creation, we must suppose that the Deity formed an archetypal plan of certain structures, and that he determined to adhere to this plan through all the modifications which those structures exhibit. But, if so, why is it that some structures are selected as typical and not others? Why should the vertebral skeleton, for instance, be tortured into every conceivable

variety of modification in order to subserve as great a variety of functions; while another structure, such as the eye, is made in different subkingdoms on fundamentally different plans, notwithstanding that it has throughout to perform the same function? Will anyone have the hardihood to assert that in the case of the skeleton the Deity has endeavored to show his ingenuity, by the manifold functions to which he has made the same structure subservient, while in the case of the eye he has endeavored to show his resources, by the manifold structures which he has adapted to serve the same function? If so, it becomes a most unfortunate circumstance that, throughout both the vegetable and the animal kingdom, all cases which can be pointed to as showing ingenious adaptation of the same typical structure to the performance of widely different functions — cases of homology without analogy — are cases which come within the limits of the same natural group of plants and animals, and therefore admit of being equally well explained by descent from a common ancestry, while all cases of widely different structures performing the same function — or cases of analogy without homology — are to be found in different groups of plants and animals, and are therefore suggestive of independent variations arising in the different lines of hereditary descent."

Blood will Tell

Everybody knows that "blood will tell," but very few of us seem to be quite clear as to just what it is that it will tell, or how. Most of us have assumed quite uncritically that there is something in the "blood" or hereditary strain that binds together all of a kind. This assumption rests on rather broad human experience and is perfectly sound, although it it not true that hereditary traits are somehow transmitted by the red juice flowing in our veins. While the blood does not carry the characters from generation to generation, we do know that it does bear distinct characteristics in an uncanny parallelism to kinship. These facts have been acquired quite recently, and could not have been known when the saying, "blood will tell," came into our common consciousness.

This new knowledge rests upon a rather subtle line of studies developed since the beginning of this century. To understand its implications and its methods, we must go back

Jean Louis Agassiz

Switzerland 1807–1873

to earlier experiments from which it was found that the invasion of the body by foreign substances sometimes produces profound modifications in the blood.

Sensitized Serum

If some white of an egg is injected into the blood of a rabbit, or another mammal, no immediate reaction follows. If, however, a week or ten days later a second injection of the albumen is made, very violent symptoms appear. We say that the rabbit has been sensitized to the given albumen. If another protein is injected this second time, there is no reaction. The animal has been sensitized to a very specific substance. The change in the blood is apparently the sort of thing that makes possible resistence to disease infection. It is the production by the body of something that *counteracts* the foreign protein, an anti-body, perhaps in some cases an antitoxin (see page 61). On the other hand, this same process of life reacting to attack gives us the distressing and sometimes serious conditions known as hay fever and bronchial asthma. In this case, the body becomes sensitized to a particular kind of protein (for example, the pollen of golden rod, the fur of the cat, and so on), and is subsequently irritated or upset when the same kind of protein is again introduced.

It may be difficult to see how a given process, which is properly described as an adaptive response to a chemical attack, can save life in one case (as in diphtheria or typhoid fever) and bring about distress in another (as in asthma or strawberry rash). If some blood of the sensitized animal is allowed to stand until a clot is formed, there is left a clear liquid called the serum. It is in this serum that we find the changed condition which is important in our investigation. The serum of the sensitized animal cannot be distinguished from the serum of the normal animal by its appearance or by any known chemical test. Suppose, however, that we add to each sample a drop of fluid containing the specific

protein to which sensitization has been brought about. Then the normal serum remains clear, whereas the serum from the sensitized animal becomes turbid. An insoluble solid is formed which settles down; this is called a precipitate. There is something present in the serum of the sensitized animal, but not in normal blood. This something combines with the protein in question to form the precipitate. This unknown something is called a *precipitin.*

Precipitin Tests

We may use a few drops of serum from the blood of a sensitized rabbit to reveal the presence or absence of a suspected protein. So sensitive is this precipitin test that a blood stain on a piece of cloth can be positively identified as being human in origin or hen's blood or whatever it is, whereas the microscope or the methods of a chemist can tell us nothing with certainty — except that there is a blood stain. The blood stain is washed out with a few drops of salt solution and a drop of this solution is added successively to each of several glass tubes containing serum from several sensitized animals. These animals had been previously sensitized, each to a different kind of protein. For example, one to hen's blood, one to horse, one to dog, one to human, and so on. All of these samples of serum will remain clear except the one that corresponds with the protein which is being tested; this will become cloudy. In legal practice this procedure is often of great importance, and has been the means of giving the court needed evidence as to the source of a drop of blood.

When this method is applied to different animals, we find that the sensitive serum has what we may call a margin of error. The blood of a wolf and the blood of a dog, for example, might both show precipitations in the same serum — there is a certain closeness of chemical nature between the dog proteins and the wolf proteins. If we take samples of other carnivorous animals and apply them to the serum

of rabbit sensitized to dog protein, we shall find this serum forming precipitations in varying degree with each sample — but more in proportion as the animal being tested is more closely related to the dog.

Blood Affinities

By extending and refining this method, special students have been able to tell us with assurance that this principle of chemical affinity as shown by the response of serum from sensitized animals runs parallel to genetic affinity as judged by structure. That is to say, the more alike animals are in their structure, the more alike are they also in their chemical composition. The more alike plants are in their form and plan of structure, the more alike are they also in the fine gradations of chemical constitution. A very extensive study of ferns, quillworts and club mosses, and other types of plants whose classification has involved many difficulties, reveals a striking parallelism between the structural resemblances, the developmental histories and the fossil records, on the one hand, and the serum tests on the other. The closeness of genetic relationships was judged by the intensity of the reactions obtained between the serums of sensitized animals and the protein extracts of a dozen representative species. The more recent work is at all points consistent with the work of different investigators who have used the serum tests in the study of plant relationship.

In comparing other groups, the student of comparative anatomy is frequently puzzled by finding a form whose relationships are obscure, or rather whose relationships branch in two or more directions. An example of this is seen in the so-called horseshoe crab, which is sometimes considered to be a kind of crab for good enough reasons, although it is fundamentally different from the crabs and lobsters in many important respects. It has no close living relatives, but in former times the seas were full of many species of trilobites (see page 30, Fig. 3). On structural grounds the horseshoe

crab has been considered more closely related to the scorpions than to any other living forms. Now comes the blood test and confirms this in a most striking way. A similar problem for the evolutionist has been the placing of birds and mammals in relation to lower vertebrates. Although birds and mammals are both warm-blooded they differ from each other as classes more than birds differ from reptiles, which are characteristically "cold-blooded." The blood tests very decidedly link the birds with the turtles, which must disturb our poetic sense, since we could hardly find more violent contrasts than are symbolized by the tortoise and the humming bird, for example.

Another example of important parallelism between the blood tests and the evidences from structure is found on comparing the whales and porpoises with cows and pigs, which of course they do not resemble for the ordinary observer. The study of whale anatomy and of whale development and of fossil whales long ago convinced the biologist that this group of animals represents a progressive divergence from an ancient stock of land animals, in adaptation to life in the water. After millions of years the whales still retain numerous structures and details of organization that link them with the ungulates or hoofed mammals, and today the laboratory discovers that in the fundamental chemical constitution they are also related to the hoofed animal.

Chemical Differences

We know very little about the fundamental chemistry of living matter. The processes that take place in protoplasm have so far eluded the most delicate chemical research. Yet we have discovered through the study of organic processes themselves the presence of substances which we can point to with certainty, although we have not yet been able to see them in a pure or isolated state. This is true of the vitamins and of the hormones or gland products which have received a great deal of attention in recent years. It is true of toxins

and of antitoxins, and it is true of numberless substances for which as yet we have not even any names. For example, bacteria of a given kind will cause disease in some animal but not in other animals. We say that a given species is susceptible to a given disease, whereas other species are immune. But we find also that this susceptibility or immunity varies in degree, and that in a given series of animals the susceptibility to disease (or immunity) will vary in almost exact proportion to the degree of relationship as judged by structural characters. We share our diseases with our nearest relatives. We seldom succumb to the disease of remote types of animals. These differences are not absolute but they are significant only because they parallel the distribution of other differences.

We see a similar parallelism in the way insect pests or parasitic fungi attack plants. The potato bug (or rather beetle) has caused havoc to cultivated potato plants, leaving the rest of the farmer's crop undisturbed. You cannot tempt these animals with cabbages or rose leaves. They will, however, eat the leaves of wild plants related to the potato. There are hundreds of insects that confine themselves to certain species of plants for food. They can be diverted from these plants in most cases only by closely related plants.

In more recent times the study of blood chemistry has revealed the presence of blood " types " among human beings, and these variations are shown to be inherited. We can apply the principles of classification not only to the structure of living things, but also to their chemical qualities, and we infer relationships from the latter on the basis of degrees of similarity.

A further line of study in which chemical constitution is found to be significant is in the differentiation of types of bacteria. These organisms are so similar and so simple in structure that very few characteristics can be recorded about their form, size and appearance. Bacteria from many different sources are quite indistinguishable under the micro-

scope. The attempt to grow these in different kinds of fluids at once reveals important fundamental differences. And these differences are consistent from generation to generation. The microscope is unable to distinguish for us various kinds of "typhoid" bacilli or "pneumonia" germs. But there are different kinds, as we can discover by growing them in tubes and by finding how they modify the life processes in an experimental animal.

Among higher plants also we find different strains that cannot be distinguished by their appearance, but can be separated by their chemical qualities. When the manufacture of black dye from logwood was still an important industry it was necessary to discover a way of distinguishing good logwood trees from those that turned out after being cut and ground up to be utterly worthless for dye production. Up to the time when organic chemistry supplanted the logwood dyes, no such method had been found. In raising sugar beets or plants for the production of drugs, the same problem appears. It has been possible to segregate and breed varieties with a high proportion of the desired substances; but this was brought about not by finding differences in the appearances of different strains, but by making chemical analyses of samples and segregating for breeding purposes those that contained the desired material in large proportions.

Convergence of Evidence

To be sure, the subtle similarities which are revealed by the sensitized serum of the laboratory animal may be merely a coincidence. The significance of the coincidence lies in its consistent appearance in thousands of cases selected from wide ranges of plants and of animals, and in the parallelism between these coincidences and the coincidences revealed by fossils in the rocks and by meaningless structures found in the bodies of animals, and of plants. The more intimately plants and animals are studied, whether in their structure or in their ways of meeting the demands of life,

the more impressed we are with the fundamental identities in detail and with the probability of kinship roughly proportional to degrees of resemblance.

However much we may wonder at the multiplicity of living forms, we accept it as after all entirely reasonable, in view of the great variety of conditions to which life has had to adapt itself — or to which living beings have had to be adapted. The marvelous adaptations presented by each species of plant and animal that we take the trouble to examine in detail are accompanied by marvelous adaptations in detail on the part of every organ and process. The same functions are carried on by different plants and animals by means of a great variety of special structures. At the same time we find that all living things are built upon a comparatively small number of general plans or patterns. This brings about the seeming anomaly that many organs which serve similar functions in many different kinds of organisms are fundamentally unlike in their development and structure, whereas numerous structures of identical origin and pattern serve a great variety of functions. We have homologous organs that are not analogous, and analogous organs that are not homologous. Moreover, in a group of organisms that present the same general plan of structure some species show certain organs in a functional state, whereas in other species they are quite without function, and may even be a source of serious harm; and in still other species such unused organs appear to be reduced to mere rudiments or vestiges.

The unity of life indicated by the identity of fundamental functions is accompanied by a unity in plan of structure extending to many details that are not in themselves significant as adaptations. There is thus raised a serious doubt as to the specific purposefulness in the origin or creation of a given species, or of all species of plants and animals. And there is thus added a strong appearance of probability to the assumption of the common origin of large groups, with modification in the course of descent.

Finally, the structural and functional characteristics on the basis of which we group plants and animals in accordance with degrees of resemblance are consistently paralleled by chemical characteristics indicating community of descent or relationship proportional to the relationship inferred from other considerations.

Chapter 5

How Living Things Come to be What They Are

> "Hour by hour we ripe and ripe;
> Then hour by hour we rot and rot.
> And thereby hangs a tale."

THE doctrine of special creation dominated men's minds for centuries. With this idea has gone the idea of distinct species as facts of nature, which assumes the existence of each kind of plant or each kind of animal in complete separation from all others. With this background for our common thought and speech, we find it difficult to think of a species changing in the course of time into another species, or of the descendants of one species coming to be in time something different. It seems too much like asking us to think that the cow may be converted into a hippopotamus or that the eggs of a snake may hatch out into chicks. Nevertheless, we do accept as a matter of course the marvel of an individual coming day by day to be a very different kind of being. We are sure of the identity of a person whom we have known for years: but no description of what he was then and of what he is now would assure a stranger that the latter is indeed a continuation of the former. Seeing a child after a lapse of years, we are for the moment impressed. How she has changed! Or is it truly the same person? One need not go into metaphysical speculation to solve this mystery of identity. We all accept as a fact the change of an infant into a child, of a child into an adult.

Preformation

When we raise the question of *how* the individual comes to be what we find him to be, we are confronted with serious

difficulties. Indeed many have solved the problem by avoiding it. They say in effect there is no becoming; what is always has been. As applied to the process of individual development, this means that whatever is actually present at one stage was also present at each earlier stage even though not apparent to the observer. This view has an ancient and honorable history. Toward the end of the Eighteenth Century it took definite form in a body of doctrine that for long obstructed scientific progress.

It is a matter of common observation that the young plant which grows out of the earth when a seed is sown was in reality already present within the seed. In the larger seeds, it is easy enough to distinguish the main axis of the young plant, the root and the shoot, with leaves and a bud. In the bud of a tree before it opens in the spring, it is possible to distinguish clearly enough the shoot and the folded leaflets which expand under favorable conditions of moisture and temperature. Although the parts of a young chicken cannot be seen in the fresh egg of the hen, it is conceivable that the structures are there. From such facts and considerations arose the notion that the individual exists already formed, but in miniature, in the egg as in the seed. Development came, therefore, to be looked upon as a process of unfolding, and it was to this process that the word *evolution* was first applied.

Within the Egg the Seed

The doctrine of preformation dominated the minds of thinkers for a long time and gave rise in its turn to another reasonable but today untenable conception. This was the idea that since the egg or the seed, presumed to contain the miniature individual, has come from the parent plant or animal, it must have existed in germ throughout the life of the parent individual, and must therefore have been enclosed in each of the preceding generations. That is to say, the whole human race was already present in the body of Eve,

like the smallest marble in the magic nest of boxes. Once the implications of this doctrine of "encasement" became clear, it became also extremely improbable. Steadily it gave way to the opposite idea: The individual develops from the egg, gradually taking form by a process of growth and elaboration: the creation of new parts from different structures.

All Life from the Egg

Aristotle made an attempt to answer the question of individual becoming by examining on successive days eggs that were being hatched. Lacking a microscope and other accessories of modern investigation, he was limited in what he could observe. He was able to find the pulsating blood vessel in the young embryo but falsely concluded that the heart is the seat of the soul. The logic is perfect, although he was uninformed as to the facts and perhaps confused as to his assumptions. If we assume that the soul (whatever we may think of it) is the essence of life, and if we assume that motion is the essential manifestation of life, it is perfectly logical to locate the soul in the heart, for it is the heart that shows the first signs of life — that is, movement.

There was not much progress made in the observation of the chick's development until the Seventeenth Century. Then there became available both better instruments and a new point of view which directed men's attention to facts and placed speculation, as a means of understanding the world, in a subordinate position. The accumulation of observations, the detailed description of egg embryos at successive stages, the reëxamination of what was actually known, led to the conclusion that all life comes from the egg.

William Harvey, who discovered the circulation of the blood, published later a collection of observations and reflections on the generation of animals. On the title page of this book Jove is represented opening a sphere from which emerge various kinds of animals, including the human form.

The inscription, *omne vivo ex ovo* — all life from the egg — was neither original with Harvey nor of the same significance as that which later biologists attached to the expression. In Harvey's mind, the "egg" was simply the germ or beginning. Today the biologist would go farther and say that every individual starts out upon life as a single cell.

In the simplest plants and animals the individual begins life as a single cell and never gets to be any more than that. In more complex animals and plants, the simple living mass divides itself into two cells, which adhere to each other and again divide, making four cells. Each of the four divides making eight, and so on. This process of cleavage or succes-

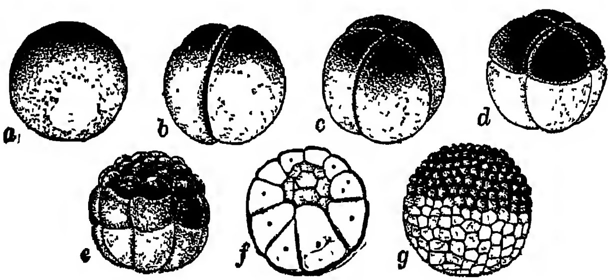


Fig 34. Early Stages in the Development of a Frog

In the frog's egg there is a considerable amount of food matter, or *yolk*, in addition to the protoplasm This yolk material is heavier than the protoplasm, and remains at the bottom of the mass So long as the cell divisions are in a vertical plane, *b*, *c*, all the cells formed may be alike; but when walls are formed in a horizontal plane, *d*, the upper cells will be smaller than the lower ones, for while all the cells may have the same amount of protoplasm, the lower ones will have larger quantities of yolk and will thus be larger, *e*, *f*, *g* From Gruenberg, Biology and Human Life, published by Ginn & Company

sive cell division has been observed in every species of animal and of plant so far studied. After the first few cell divisions the further development proceeds along a variety of paths.

If we follow a single frog's egg we may see the formation of a ball consisting of several cells. The ones near the top of the sphere are smaller than the lower ones. Although the first four cells were indistinguishable there gradually appears a differentiation. In some parts of the mass the cells increase in numbers more rapidly (see Fig. 34). If we follow another frog's egg we shall find exactly the same procedure up to the point where a tadpole is clearly discernible, and a third

frog's egg and a fourth will develop in exactly the same way as our first, and also the fifth and the tenth and the thousandth. While a frog's egg does not look like a frog, or even like a tadpole, it is nevertheless all frog and only frog. It is as much a part of the "species" as is the adult.

Specific Resemblances at all Stages of Life

It may seem childish to repeat this. Of course, you will say, one frog develops as does the next one. One chicken develops like another one. One human being develops like another human being. We asume this as a matter of course. But why? We do not pretend to know just what makes the animal change day by day as it does, but we are quite sure that the sameness of the members of a species extends to their development as well as to their adult form and structure. A frog is like other frogs at every stage of its being. A clam is a clam at every stage of its being.

Just so. And although nobody has seen all the frogs or all the clams or all the hens at every stage, it is common sense to think in these terms. If we have seen the caterpillar of the tomato worm we assume that the next similar tomato worm is also the larva of the same kind of insect. If we have seen the grub of the June beetle we assume that the next similar grub is also the larva of the June beetle. In the same way we recognize hens' eggs as hens' eggs even if we were not present when they were laid, even if we do not wait to see into what they will hatch.

These facts are so familiar that we are apt to overlook their implications. Yet they have an important bearing on the question of relationships among different kinds of animals or plants. To the extent that we accept descent from a common ancestor for all the June beetles or for all hens or for all green frogs, we accept of course the same relationship for the June bug larva or for green frog tadpoles. If we knew the tadpoles only and never the adult frog, we should never hesitate to think of them as the "same kind" of animals, and we should infer from their resemblances a common

ancestor. The student of embryology applies this same method of reasoning in dealing with plant and animal embryos at every stage of development. *In so far as two embryos resemble each other, they are taken to indicate a common ancestor.*

We all know that a calf will grow into a cow, barring accidents; that a colt normally becomes a horse. We have seen puppy become dog in enough instances to feel warranted in extending the general idea to other puppies. And we have seen the transition from infancy or larva to adult in enough instances to extend the general idea to all animals — even to animals we have never seen. In passing from the egg to the adult, each individual goes through a series of stages in common with other members of the species. Again we infer relationship proportional to the degree of resemblances at the various stages. An experienced breeder will distinguish a Plymouth Rock from a Rhode Island Red while the two chicks still look alike to the layman. Yet the layman will have no difficulty in distinguishing the two chicks from young ducklings. A dog fancier will distinguish various breeds of dog before the puppies have opened their eyes although all puppies may look alike to the rest of us.

Relatives Have Similar Babies

If we compare the successive stages in the development of a frog with the early stages in the development of a toad, we find correspondence in great detail. In most cases we should not be able to distinguish the young tadpoles of different species, except perhaps by the size. They are in form and proportion practically identical. To the extent then that these animals are alike in their development we may consider them related — even if we do not wait for the maturing of the individual. For most people, in fact, frogs and toads are indistinguishable terms. It is sufficient for most of us to think that the toad is "a kind of frog." And it is sufficient for most of us on seeing a tadpole to assume that it will some day be "a kind of frog." But similar stages in develop-

ment are to be observed in newts and salamanders. In these animals also there is a passing from the egg to the tadpole. Here also the tadpole lives in water, breathes through gills. Here also the tadpole is gradually transformed into an animal with legs and without gills, breathing through lungs. On the basis of these similarities, we group the newts and salamanders with the frogs and toads as batrachians or amphibians — and assume their relationship.

Water-breathing Vertebrates

The class of animals known as fishes includes the most familiar and characteristic water animals. In fact, we are for this reason often inclined to apply the name " fish " to types of animal that are not fish at all, like jellyfish, cuttle-fish and starfish — representatives of three diverse branches of animal life. In common with all backboned animals, indeed with all other animals, the fish starts life as a single cell — the fertilized egg. As in other animals this egg cell divides into two, and each of these again into two and so on until numerous cells are formed. Hour by hour one can see new cells formed, the parts gradually taking on the appearance of distinct structures, and after a time it is possible to recognize the entire mass as resembling " fish."

During this early period of development the successive stages are remarkably like certain stages in the development of the frog. It is no stretch of the imagination that makes us compare the tadpole of the frog to the young fish. In both animals there is the same general form. There is swimming by the action of the tail. There is breathing by means of gills. Internally also the tadpole resembles the fish in many details. The young fish, however, remains fish-like as it grows older. We may say that the adult fish is the same as the young fish only more so. The tadpole, on the other hand, diverges from this pattern as it grows older. The buds on the side of the body, which in the case of the fish become fins, grow in the tadpole into legs. The tail is gradually

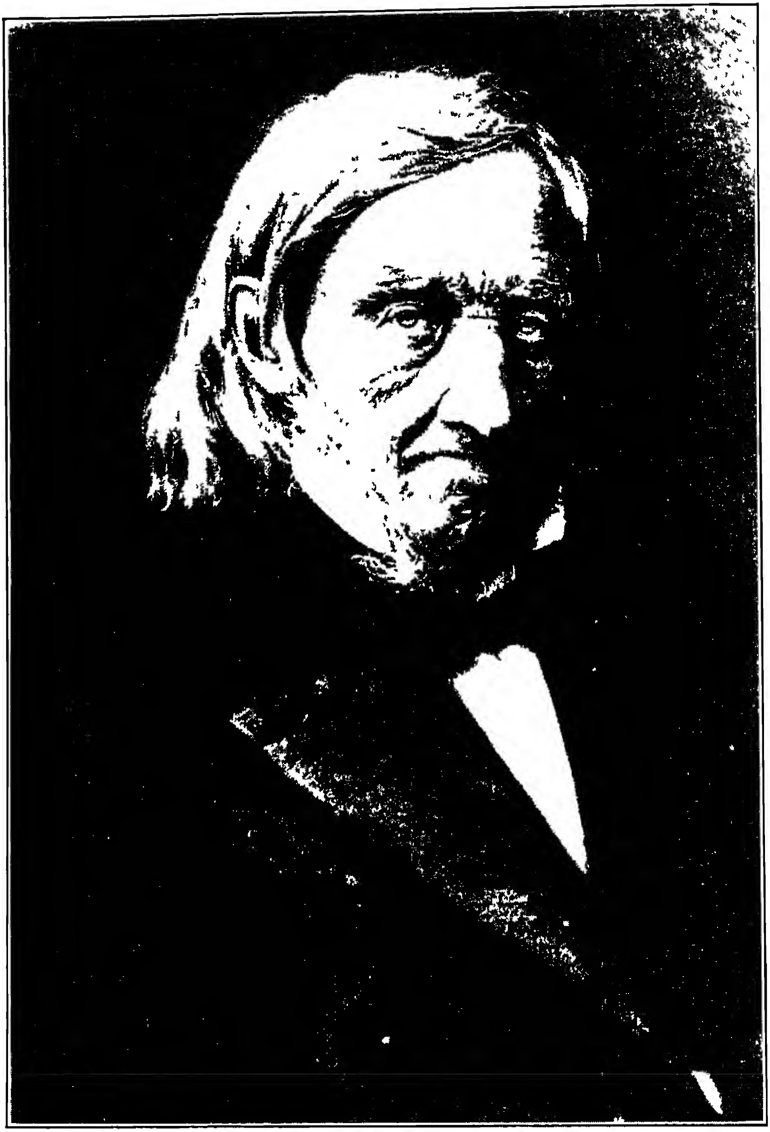
absorbed. The gills are also absorbed. An air sac connected with the food pipe is present in both fish and tadpole. It becomes in one case a pair of lungs but remains in the fish merely an air bladder.

The frog, on its way from being a one-celled water animal (the egg) to being a land animal with four legs and a pair of lungs, resembles a fish on its way from being a one-celled animal (the fish egg) to being a backboned water-inhabiting gill breather. This resemblance persists for only a part of the individual's development. However, so far as this resemblance does persist we infer a common ancestry.

Gill-bearing Land Animals

In addition to the fish and amphibians there are three great classes of backboned animals — the reptiles, birds and mammals. Any individual member of one of these classes, in common with the fish and the frog and in common with all other animals, starts upon life as a single cell, the fertilized egg. The reptiles usually deposit their eggs, with more or less of a horny shell containing more or less concentrated food, on the ground or in a burrow; and leave the hatching to the heat of the sun and good fortune. The birds typically give birth to their offspring as minute eggs enclosed in limy shells containing a comparatively large mass of reserve food (the yolk and the albumen) and typically supply protection and heat during the development of the individual within the shell. In the mammals the minute egg develops within the body of the mother until the embryo is at a relatively advanced stage.

In all three classes the egg divides into two cells, each of which again divides into two making four, and each of these divides, and so on, until there is formed a thin layer of cells which gradually becomes elongated so that it is possible to distinguished the head end from the hind end. This layer of cells doubles and wrinkles and folds, acquiring a distinct appearance, but not resembling any known animal. If we com-



Karl Ernst von Baer

Esthonia 1792–1876

pare the turtle and the bird embryo day by day it is impossible to distinguish the two for a considerable part of the development. If we compare the bird with the mammal day by day it is impossible to distinguish the two for a considerable part of their development. At one point in all three classes the head is easily distinguishable. Immediately behind the head there appears on the side of the neck a series of wrinkles quite similar to those found in the fish embryo (see Fig. 35). In the fish embryo these wrinkles open asunder and the spaces become clefts or openings connecting the pharynx with the outside. In the developed fish these openings are the gill slits through which passes water, carrying oxygen over the gills. We can see here the development hour by hour of the fish's breathing apparatus. This includes not only the openings through which the water passes but also the gills through which the gas exchange takes place and the large blood vessels that carry the blood to and from the gills.

That a similar development is found in the batrachians seems quite reasonable since, as we have seen, these animals are fish-like in their habits at a certain stage. They have gill arches because they later have gills. Harder to understand, however, is the presence of these same wrinkles in reptiles and birds and mammals. There are present not only these "gill slits" but also the blood vessels corresponding to the gill arches — and tiny neck ribs which are later absorbed. On no theory of special creation or of purposeful adaptation can we account for these essentially water-breathing structures.

In the adult individual of any of these classes there remains only one relic of this elaborate and useless and roundabout development. This is the tube connecting the pharynx with the inner ear — the eustachian tube. We become aware of the effectiveness of this tube when a rapid change in atmospheric pressure or a very loud sound makes itself felt in the ear. We are advised to "swallow rapidly," or to keep the mouth open, to prevent injury to the eardrum by a cannonading, or by a rapid descent in an elevator, or by a

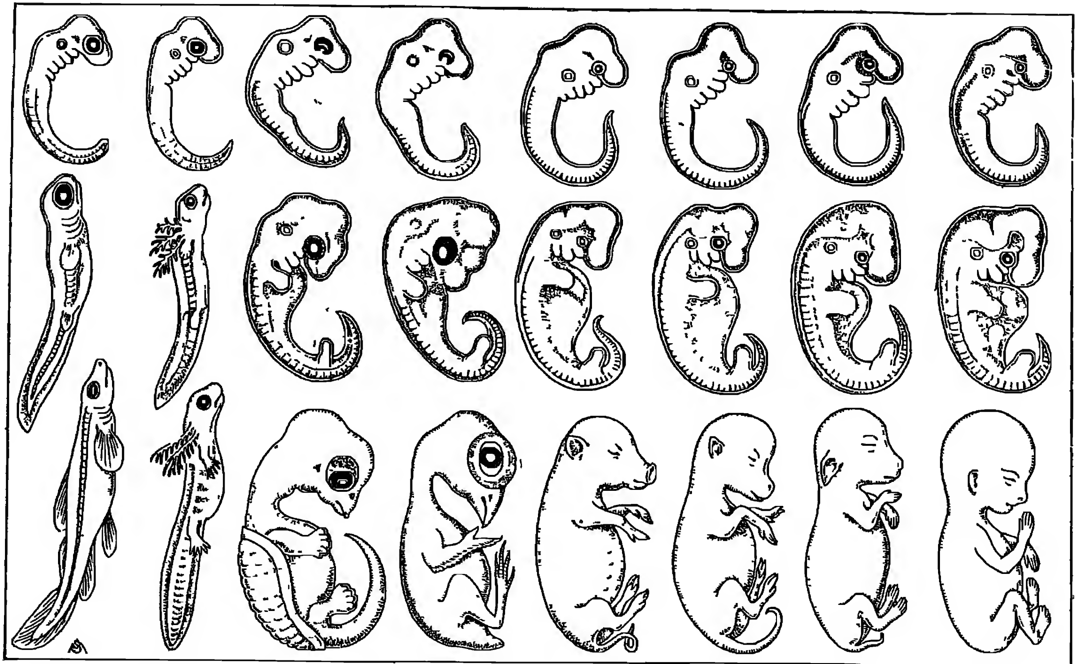


FIG. 35 PARALLELISM IN DEVELOPMENT OF BACKBONED ANIMALS

The three rows of embryos represent distinct stages of development In the first row the stages of the different species are very much alike, in each succeeding stage they are more distinctive From Gruenberg, Elementary Biology, published by Ginn & Company

trip in a deep tunnel. The eustachian tube permits the air pressure on the inner surface of the eardrum and that on the outside to become equalized. The whalebone whales dive to such depths that if they had eustachian tubes the high pressure would burst the eardrums. Curiously enough, they have long ago given up this last vestige of the gill-cleft, as we can judge from the fossil remains of the Eocene period. Yet every new whale, in developing from an egg to a baby whale, still goes through the motions of wrinkling up the sides of its neck into make-believe gill slits, like other mammals, and birds, and reptiles — and fish.

The Biogenetic Law

The facts of development among the vertebrates received intensive study in the early half of the last century. The foundations for comparative embryology were laid by Carl Ernst von Baer in 1828. One of the first generalizations that came from these comparative studies was the parallelism in development among animals of similar type. In general, it is true that the more alike two species are (in their adult stages) the more alike are they also in the successive stages of development. The more the adults differ, the earlier in their development will the embryos diverge in appearance and structure. This has been found to hold for all groups of animals, not only the vertebrates.

Under the influence of the enthusiasm for the evolution doctrine there was formulated the "biogenetic law," which says in effect that each individual in the course of development passes through a series of stages corresponding to ancestral types. This principle was overworked to such an extent that it finally became an impediment to research and understanding rather than an aid. After all it is not true, no matter what we may think of the origin of species, that the human being, for example, in the course of its development is at one point a fish or at another point an amphibian. At most, we may say that at one stage in its development

the human embryo resembles a certain stage of the fish embryo, of the chick embryo, of the turtle embryo. In a group of classes having the same general plan of structure the embryos pass through comparable stages. The individual embryo of one class resembles the individual embryo of another class up to a certain point, when divergences appear. But at no time does the embryo of one class represent the adult of another class. The bird and the rabbit develop as does the fish up to a certain point. Past that point the bird and the rabbit embryos pursue a different course, leaving the fish embryo to develop into a fish. The bird and the rabbit embryos, on the other hand, continue a common course still further and diverge from each other later, one to become a bird and the other a rabbit.

The Meaning of Embryonic Structures

The biogenetic law has had to be qualified as a result of accumulated knowledge. We see now that it is impossible for the individual in its brief lifetime to recapitulate the whole history of life upon earth. While it is true that the individual passes from a one-celled stage to the adult stage as did the whole race, according to the evolutionary doctrine, the process of development is necessarily so condensed that we cannot expect a complete recapitulation. More important, however, is another set of considerations. Theoretically each ancestor in any genetic line must have represented a type of animal capable of living at large in its own surroundings. In the development of the individual, especially in the case of the higher animals, the embryo does not live an independent life. It must be adapted to the particular conditions under which it develops. The fish, for example, swims about freely, captures food and evades enemies more or less successfully. The embryo of a bird or of a mammal does not do any of these things. The food is supplied by the reserve in the egg in the one case, by the blood of the mother in the other case. The organism is

sheltered, and it cannot move about either in flight or pursuit. In animals like the insects, the problems of adaptation means at each stage a mode of living that cannot be identical with that of hypothetical ancestors or real ancestors.

With all of these qualifications, however, there remain facts that do not lend themselves to interpretation except on *the assumption that there has been modification of types in the course of descent.* Embryos of all classes of animals are found to contain structures which are meaningless if we think of a purposeful adaptation of either the embryo or of the adult. But these structures agree in detail with the assumption of descent with modifications. The ruminants like the sheep, cow, buffalo, deer and camel have no collar bone in the adult stage. In the embryo of the sheep, the beginning of such a bone is formed. Before the animal is born this is absorbed. Adult whales differ from other mammals in having no hair covering on the body. We may accept this fact as quite in keeping with the theory of purposeful adaptation since these animals living in the water have no need for hair, although the seal and the otter and beaver, also living in the water, have the finest fur in the world. The whale has, besides, a thick layer of blubber which protects adequately against changes of temperature and loss of heat. In the fetus of the whale, however, there is a rich coat of hair, which disappears before birth.

The scarcity of hens' teeth is proverbial, and no modern birds have teeth although the fossils of the earliest unmistakably bird-like animals so far found (the archeopteryx) show unmistakably tooth-like structures. Later birds also had teeth as the record in the rocks tells us. While adults of modern birds do not have teeth, the embryos of many species of birds have the germs of teeth, definite beginnings while still in the egg, and lose them before emerging from the egg. The hind legs of the Greenland whale have a definite hip bone and thigh bone and a shin that never get out far enough to reach the water (see Fig. 27). In the fin-back whale, there is a reduced hip bone and a bit of the thigh bone.

The earliest mammals found in the rocks appear to have, typically, forty-four teeth. Many of the modern mammals have greatly reduced numbers. Among the rodents or gnawers (rats, rabbits, squirrels, gophers, etc.) there is a gap between the front gnawing teeth and the grinding teeth. Yet the embryo of the squirrel shows beginnings of teeth in this gap. In toothless whales, a study of the early stages shows the presence of teeth in the jaws; but these are absorbed before birth.

Facts like these are taken to mean that whalebone whales are related to the toothed whales; that rodents had ancestors in which there was not a gap between the incisors and the pre-molars. In the same way, we observe that the embyros in many beetles bear appendages on all the segments or rings of the abdomen, whereas the adult beetles bear legs only on the thorax, like other insects. And we take these facts to point to a relationship with a more primitive or generalized type in which the parts of the body were not so sharply differentiated.

Embryos as Missing Links

Increasing familiarity with the facts of animal structure and development leads us to accept relationships within groups that are obviously similar in form and structure, or even in general plan of organization. We still have difficulty, however, in considering animals of distinct types as related. There is nothing in the structure of any backboned animals to link up with the invertebrates. The segmented worms may conceivably be related to the arthropods, since the larval stages of most insects are very " worm "-like. But the other main branches appear to be so distinct that even the biologist is puzzled to find possible transitions or connecting links. The study of embryology has yielded some very striking evidences of relationship.

The mollusks, which include clams and oysters, snails and periwinkles, squids and octopuses, represent a rather

distinct group. While the three classes of mollusks have a great deal in common, they all differ from other branches so much that it is difficult to find convincing affinities. If, however, representatives of these classes are studied from the point at which all animals are alike in structure, namely the one-celled or egg stage, significant facts appear. After the segmentation of the sand-worm's egg has passed the two-layered stage, certain regions of the cell mass put out vibratile hairs or cilia by means of which the embryo can swim (Fig. 36). There is developed a free swimming larva called the trochophore which resembles no adult animal we know, except in a general way the "comb bearers," sometimes mistaken for jellyfish. The resemblance here is very general: there is a sac-like body with rows of cilia extending along the side between the poles. As the trochophore of the worm is closely watched in its development, we see changes which hour by hour elongate the body in the region farthest from the mouth. The ring of cilia becomes crowded forward and the cilia themselves eventually disappear. The elongated hind part becomes constricted into rings or segments, each of which has a portion of the "body cavity" and a segment of the food tube, as well as portions of the main blood vessels and of the nerve strands.

We do not know why the worm develops from the egg in this roundabout way; but the facts are clear. If we follow the development of a clam's egg or a snail's egg we find again after the two-layer stage the formation of a trochophore. With the hundreds of species of mollusks and of segmented worms living in the ocean, there are at times millions of trochophores floating about, and it is impossible for most observers to know the larvæ of different species apart, or even the larvæ of worms from the larvæ of mollusks. Different as the clam is from the worm, both are alike not only in the one-celled stage but in the trochophore stage. From this point on the individual oyster or clam follows a different path from that of the worm. The iden-

tity of the earlier stages, however, is impressive; and if it has significance, it must point to common ancestry in some remote past. Strangely enough, some of the fresh-water worms whose eggs develop inside of capsules or cocoons, where they never have a chance to swim about and get food for themselves, also pass through the trochophore stage.

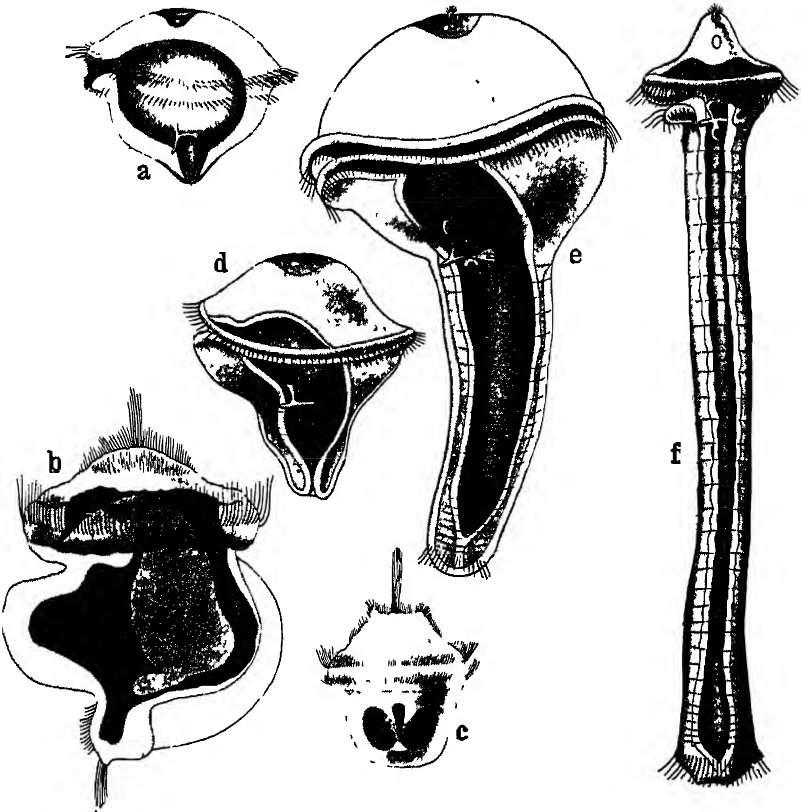


FIG. 36. COMPARISON OF MOLLUSK AND WORM

A clam is not readily mistaken for a sandworm In the early stages of development, however, the mollusks and the segmented worms pass through a curious stage called the trochophore, *a* Millions of such trochophores swim about in the water, representing many different species of mollusks, and many different species of worms. As the mollusk trochophore continues its development, it acquires distinct structures, *c*, and the clam larva, *b*, with the beginning of its two-valved shell, is readily recognizable The worm trochophore elongates, *d*, and gradually acquires a longer body, *e*, which is at last worm-like and segmented, *f*

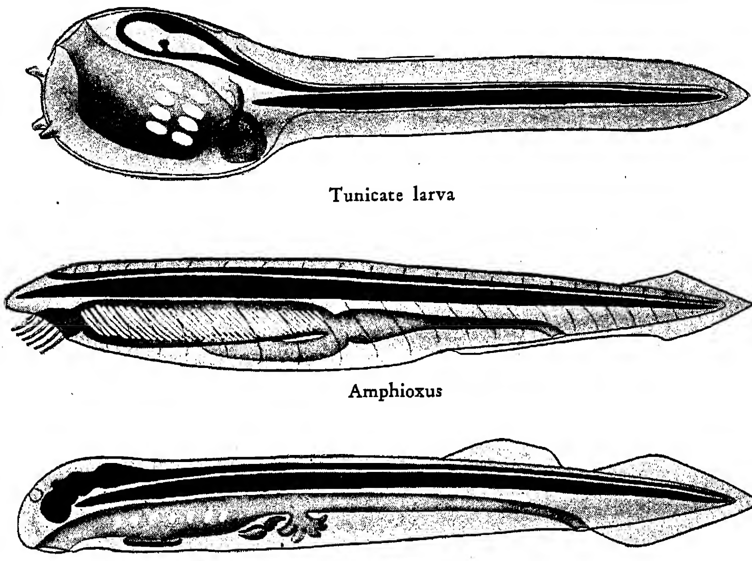
The Origin of Vertebrates

The probable origin of the vertebrate type has been a puzzle to biologists even if they readily accept the doctrine of descent from different forms. In two generations, however, there have been accumulated facts regarding the development of many types of animals; and these point to affinities that had not been suspected. In the development of the backboned individual, there is formed a gelatinous rod running the length of the embryo, the notochord. This serves as the basis for the subsequent development of the backbone although it is not itself either a backbone or a part of the backbone. There are some minute water animals — " worms " in general appearance — which also develop a supporting structure. These have been combined by some zoologists with true vertebrates into a more comprehensive group called Chordata. One of this group, the amphioxus or lancelet (Fig. 37) shows very definite affinities to " worm-like " forms on the one hand, and to the early stages of backboned animals on the other. Moreover, the sea squirts, a group of sessile animals that we should be less likely to look upon as possible ancestors of the vertebrates than clams, show in their development very close resemblance to the amphioxus. While nobody can say that the vertebrates as a group are descended from the simpler chordates, or that the lancelet and acorn worm are descended from an animal like the sea squirt, these close resemblances during the early embryonic stages are certainly impressive. We can only say that the respective groups have a great deal in common early in life. The Russian biologist, Alexander O. Kovalevsky, pointed out that these groups have so much in common during the early stages that the formation of degenerate adult sea squirts and the development of young fish proceed normally from practically indistinguishable larval structures.

Development of Parasites

Many parasitic and degenerate animals present particular difficulties in our attempt to classify them. The barnacles

were for many years a puzzle to naturalists, as well as a nuisance to mariners. They were supposed to be related to mollusks; they were supposed to fall from the trees; and many other myths about their origin and relationships grew up. Darwin, by studying the development of barnacles from the egg, showed that they are unmistakably crustaceans, crab-like animals which adopt a sedentary life



Tunicate larva

Amphioxus

Lamprey

FIG. 37. PROPHETIC OF VERTEBRATES

The sea squirts are hardly suggestive of anything higher than sea anemones or clams. The larva (above), however, has the beginning of a cord and a dorsal nervous system. The amphioxus or lancelet is worm-like in appearance but it has a flattened fish-like shape and a definite supporting cord. The lampreys do not develop a bony skeleton, but they look like eels and breathe like fishes.

under special conditions and come to be in the adult stage quite unrecognizable as crabs. There is sometimes found on the abdomen of crabs a parasite consisting of a sac which sucks up the juices of the host and thrives upon them. This sac is almost shapeless and has no distinct structure by which we might recognize its relationships to other types of animals.

A study of the life history, however, shows very clearly that it too is a crustacean in the early stages and degenerates into an almost structureless sac, after adopting the parasitic habit (see page 108 and Fig. 33).

Are we to classify the barnacle and the Sacculina on the basis of their adult form, or is it reasonable to take into consideration the entire life history? If we do the latter, we assign them a place among the arthropods which they do not at all resemble as adults. If, however, we may accept the embryonic stages as indicative of true relationship in these animals, we must consistently do the same in other groups.

Embryos and Fossils

We cannot escape the fact of similarity between the embryonic stages of animals that in the adult represent distinct plans of organization. We may not go so far as to say with Haeckel that ontogeny or individual *becoming* repeats phylogeny or the evolutionary history of the race, except in a most general sense. It is sufficient to see that embryos of recent and more highly specialized animals are survivals corresponding to the embryonic structure of lower forms. We need not say that the human embryo passes through a fish stage. It is enough to say that both the human embryo and the fish embryo, as well as the reptilian and bird embryos, pass through similar stages.

There are, however, striking similarities between the embryos of higher animals and the adults of earlier levels of organic evolution. Louis Agassiz, who like his master Cuvier was opposed to the idea that species change, or that present-day forms arose by diverging from ancestors in structure, nevertheless pointed out that the stages in the development of all living animals correspond to the order of succession of their extinct representatives in geologic times. This was in 1858, the year before Darwin published his *Origin of Species*. His own son subsequently confirmed this generalization by comparing in detail the series of fossil sea

urchins with the successive stages in the development of living species, revealing a remarkable parallelism.

Many such parallelisms between the embryonic stages of late forms and the succession of earlier fossil forms have been pointed out. One particularly interesting example is presented by the fossil series of ammonites, animals resembling the nautilus, and young stages of later forms also found in the rocks.

Divergence in Human Development

We accept the human race as one "species," taking for granted a common origin, whatever we may think of evolution. The facts of human development, when comparisons are made among the various races, show as we should expect a consistent parallelism from stage to stage, notwithstanding the marked differences which we see among the adults of these races. More intensive recent studies show further that the earlier in its development an embryo is examined, the more does it resemble other human embryos; the older the embryo, the more distinct is it, the more individualized. Moreover, where careful measurements have been made it is found that the embryos of different races diverge more and more from each other as they advance in development. The embryos of a given race will progressively differ more from embryos of another race, as they grow older. Never is there any evidence of convergence, or of becoming more alike.

Careful measurements of the various structures in human and other primitive fetuses show that as growth proceeds the shape of the head, the proportions of the limbs and other features become increasingly different, as between one species and another. For a period the ratio of one organ's dimension in two forms may remain the same — but the differences noted at one point never become less. Whether it be the feet or the hands, the jaws or the brain box, whatever parts are compared in the embryos of two different species of primates become progressively more different from each other as development goes forward.

These parallels in *divergence during development* call for an explanation in terms of a common set of causal factors. We may suppose that living matter, present in the living egg of any animal, must pass through certain stages in order to become an adult, regardless of how any species originated. Mammals, for example, must have their embryos behave during development just as they do because they must at each successive stage be adapted to living within the womb of the mother, to getting nourishment from the mother's blood, to breathing and elimating wastes by means of the mother's blood. Many of the structures and processes observed in the developing fetus are indeed remarkably adapted to this specialized mode of life.

It may satisfy many to say that the embryos develop as they do because that is the most suitable way of passing from the one-celled egg to the billion-celled adult. Such an explanation, however, leaves open the major problem. Why does the embryo start to produce structures that serve no function whatever, either during development or later, many such structures that are in fact later lost? Why must the very young person, for example, grow a tail only to lose it again before meeting his mother face to face? Why must the embryos of air breathers start out to elaborate water-breathing organs and then change their course and lose most of the evidence of the abortive attempt before they begin to breathe on their own?

The evolutionist's explanation for these facts is found in the supposition that species arose by progressive divergence from ancestral types. The development is a manifestation of heredity, not in the sense of Ernst Haeckel's extreme doctrine of recapitulation, but in the sense that in so far as two or more species are actually related through common descent, they will show a similarity in the stages of development as well as in the adult form. The more closely related two individuals are the longer will they remain alike in progressing from the earliest indistinguishable stages. The less closely related two individuals are, the earlier in their development will differences between them appear.

Development in Plants

It has not been easy to apply the biogenetic law to the development of plants, because the earlier stages in the development of higher plants have come to be well known only in more recent times. Moreover, in the earlier stages of their development, plants do not manifest such distinctive and characteristic structures as do animals, so that comparison has been difficult. And finally the life cycle of all plants above the mosses and liverworts shows peculiarities that make impossible the kind of comparison which has been so fruitful in the study of animal development.

As knowledge increases, however, the same general principles appear. Every plant individual starts life normally as a single cell. Cell division results in increasing the number of cells making up the body mass. New structures appear by elaboration and specialization of cells. The early stages of the highly developed plants correspond in many respects to the structure characteristic of lower types of plants. In the lowest plants sexual reproduction takes place in the water, as is the case in the simplest animals. The gametes (germ-cells, eggs and sperms) come together by floating or swimming in the water.

The liverworts, mosses and ferns live upon land, although, like the amphibians among animals, they must return to the water during part of the year in order to make fertilization possible. This does not mean that mosses and ferns move into the pond when spring comes, as do the frogs. It means only that in these plants the stages during which sexual reproduction takes place are low or flat and depend upon being submerged by rain water, or even by a few drops of dew in some cases. In this condition the sperm cell can swim toward the enclosed egg cell. With higher plants the sexual phase is reduced still further, and the parent plants manifest a great variety of adaptations to the need for bringing the sperm and egg together. In the flowering plants the sperm floats in a

delicate thread of semiliquid protoplasm that grows from the pollen grain to the heart of the egg-bearing structure, the prospective seed.

Particularly impressive are certain details in the reproductive processes of plants that stand between the higher ferns and the seed-bearing plants — the cycads. These show a combination of a primitive swimming sperm with a type of egg-bearing structure approaching the seed plants. In recent years the study of plant embryology has grown rapidly and all the findings are in agreement with the supposition that more highly specialized types arose as modifications of simpler types.

All the facts of development, then, point to this: the individual diverges progressively from other individuals as he grows from a primitive, simple, one-celled being. Parallel facts suggest that races of one species diverge from a common form. The facts finally show a parallel process of divergence from a common type by different species of a family, by different families of an order, by different orders of a class, by different classes of one of the main branches.

It is conceivable that the inhabitants of the earth are descendants of substantially identical ancestors created in the first instance as adults capable of reproducing themselves in their own image. It is impossible, however, to reconcile this assumption with the million facts today known about individual development from the egg unless we invent an endless chain of supplementary theories to account for these facts in detail. We must either assume that the creative deity is a capricious being who works in an arbitrary way his wonders to perform, or that there is order in the universe of life.

> "Hour by hour we ripe and ripe;
> Then hour by hour we rot and rot.
> And thereby hangs a tale."

The other name of this tale is evolution.

Chapter 6

Changing Plant and Animal Nature

THE so-called evidences of evolution so far discussed are what the lawyer would consider indirect or circumstantial. Is there any direct evidence of the transformation of species?

If plant and animal forms have in the past become modified in the course of descent, there is no reason to think that the processes have ceased. The processes which may have resulted in the rise of new plant and animal forms should be observable now. The only qualification which may have to be considered is that of time. The supposed evolution of the forms whose records are fairly complete must have taken thousands and millions of years. Our observation can be applied to a negligible fraction of such a time. The slowness of the process, however, does not relieve the biologist of the responsibility for capturing the facts. The astronomers have been able to measure movements of the "fixed" stars which to the ordinary observer are indeed fixed in their relative positions from century to century. They have also been able to measure a wobbling of the earth's axis which completes its circuit in 25,000 years. The physicists have been able to measure the disintegration of heavy elements like uranium as fractions of a process extending over millions of years. The geologist, dealing with earth changes that have taken millions of years, can find and measure the processes involved as they go on before our eyes. In the same way, the biologist has been able to catch the process of evolution in the act, so to say.

No Two Alike

As one travels about and sees farmyards and the backyards of various homes he can recognize domestic animals as pigs and chickens, cows and horses, sheep and geese. In spite of the differences between the cows on one farm and those on the next, we think of them all as of the same species. We are not astonished by the great *variations* in the scrub animals or by the great variations that we see at a dog show or at a county fair. We feel that it is of the nature of "dog" to be all the different-looking beings that we see. In some regions or on some farms we may observe a considerable uniformity among the cows. Again we are not astonished at the *uniformity* of these animals. We ascribe this uniformity to better breeding, or to careful selection of stock, without inquiring too closely into the methods by which it has been brought about, or into the meaning of the process. We feel that it is in the nature of white Leghorns or of polled Herefords to be fairly uniform. We see many different kinds of apples or plums or grapes, and we take the variety as a matter of course. And when we see the uniformity of a particular lot of apples or grapes we again take this as a matter of course.

The persistence of characters which is recognized in our concept of heredity combines with the equally persistent variability of living things to produce a moving equilibrium. This is from one point of view the life of the individual, and from another point of view it is the evolution of species. In the case of the individual, preservation of identity during constant change involves an effective adjustment to the surroundings. In the case of a species or a race there is genetic or germinal continuity and change in the course of time, with adaptation at every point to the conditions of existence.

This presentation of the life of the individual and the life of a race is not a mere metaphor. Our very concept of species involves fitness just as does our concept of life in the individual. We are concerned with distinct groups of animals that are capable of living and of maintaining them-

selves independently from generation to generation. It is not sufficient for our purpose that the individual merely deviates from the pattern of his species — mutilating and destructive effects of disease and injury yield deviations enough. It is not sufficient that individuals be born that diverge from the parental pattern — monstrosities are common enough. It is necessary for our purpose to find deviations from the pattern set by the species and divergences from parental models, *that are at the same time capable of living and of perpetuating themselves.*

To be able to recognize evolution taking place, we must consider the facts of adaptation as well as the facts of variation and of heredity. The inhabited parts of the world show great extremes of physical and chemical conditions — of degrees of moisture or dryness, of heat or cold, of light and shadow and darkness, of chemical composition, of concentration and of proportions of various substances. In all of these varied conditions, we find living things, animals as well as plants, and many living things of which we cannot say definitely that they are either plants or animals. In the various dwelling places or habitats, these living forms differ from one another. The plants and animals of the water are unlike the plants and animals of the land. The inhabitants of the desert are unlike those of the plain or of the swamp. The plants and animals of fresh water differ from those of the salt sea, and those afloat in the water at large differ from those along shore or in the depths.

In every situation, however, we observe that the living things are somehow *fit to live,* they show adaptation. Their structural and functional peculiarities are suited to the habitat. A part of the problem of the origin of species is to find out just how living things come to fit so remarkably well their respective abodes.

Fitness of the Environment

We are disposed to take for granted the physical world as something fixed and final, and to think of fitness as a one-

sided matter. A thing is fit or it is not. A little reflection, however, will show us that from the very nature of the idea fitness must be a matter of mutuality. We need constantly to be reminded that so far as concerns "life," the physical environment also shows a remarkable fitness. The physical and chemical properties of water, both in its gaseous and in its liquid state, the characteristics of carbon and of nitrogen and of the other chemical elements that enter into the composition of protoplasm are admirably adapted to bring about between them all the distinctive characteristics of living matter. If there were no water, or if its freezing and boiling points were considerably different from what they are, there could be no life, such as we know. We may say the same of each of the other important physical factors, such as the light and heat from the sun. Life being what it is, it can arise and perpetuate itself only in our kind of material world.

On the other hand, it is just as true to say that the world being what it is, it can maintain only the kinds of life which we find in the actually living plants and animals. The environment is fit for life — this kind of life. Life is adapted to the environment of this kind of world. But this world is itself constantly changing, within certain limits, in all details. Being alive means maintaining a constant change in response to these external changes and in some special relationship to them.

Specific Relations of Fitness

From what we know of living processes, we can see some of the directions in which organisms must be adapted. The getting of food, of water and of air, are primary conditions of living for practically all organisms. We are impressed with the fact that the one-celled plants making their food out of water, carbon dioxid and salts, live on exposed surfaces in the air, in fresh water, and in salt water, whereas there are complex plants sometimes of enormous size also living on land, in fresh water and in salt water. There are one-celled animals that feed on bacteria, ferocious beasts of

prey, mild grazing animals, insects sucking nectar from plants, starfish everting their stomachs and insinuating them between the shells of the oyster, the whale catching food by swallowing a couple of hogsheads of water and straining out thousands of smaller beasts. Endless varieties of food-getting organs and processes can be found in one class of animals alone like the insects or birds.

There must be fitness to get water and at the same time protection against being drowned out. Every plant, in so far as it is a food maker or contains within its body nutrient materials, becomes exposed to attack. Every animal is exposed to attack from larger or stronger animals as well as from smaller and more subtle enemies. Protection through toughened skin, through hairs and spines, through bark and hide, through armors and shells, through stings and darts and poisons, are found on every hand.

The danger of excessive heat, the danger from drouth, the danger of excessive cold, are met in myriad ways. Some of the structures or arrangements that protect against mechanical injury, such as hides, armors and furs, may serve also to protect against excessive changes in temperature and moisture. The feathers of the bird combine perfect insulation against changes in temperature with extreme lightness. Desert plants show typically reduced leaf and stem surfaces. Many plants and animals go into winter quarters and some, by encasing themselves in cysts or capsules, lie dormant until conditions for activity are more favorable. The shedding of leaves in the fall may be looked upon as a form of protection against the unfavorable conditions of winter weather, since it reduces enormously the exposed surface.

Color in nature impresses itself upon the casual observer primarily perhaps because of æsthetic interests. One cannot go far afield, however, without discovering in color suggestions of adaptive values to the individual plant or animal. We have all been startled by the movement of a frog or a bird that remained quite invisible, or at least in-

distinguishable, until we approached close enough to startle it. Many an idle rambler has reached for a leaf or twig only to have it fly away from under the hand. The flatfish is indistinguishable in the water when resting on the bottom. Insects match the leaves and bark of the plants upon which they rest in a manner that must at least in many cases serve to protect them from possible enemies. The practice of camouflage during the World War was developed entirely from observations made upon the protective colorations and patterns of living things. It is true that many of the colorings found in plants and animals are incidental to the chemical constitution of their food and to the chemical processes that go on within their bodies. It is true also that there are many colors that can have no conceivable connection with advantage to their bearers. Yet there remains a substantial body of truth in the assumption that color, as well as form, may often have adaptive significance in the life of many plants and animals.

Preservation of the Species

Adaptations to reproduction include a wide range of structures and processes that have always fascinated the student of nature. Many water plants and animals discharge their eggs and sperms into the water where fertilization is largely a matter of chance meeting of two germ cells. Millions are called but few are chosen. In other cases, there is an increased probability of mating through special structures or special modes of movement, or through responsiveness to special stimuli. The adaptation of flowers to the visits of birds and insects and the complementary instincts of the insects and birds, which bring about cross pollination for the flowers while supplying food to the visitors, have impressed the thoughtful as truly remarkable. The details of structure and markings in some of the orchids and their relation to particular species of visiting bees or butterflies are most exquisite.

The instincts of birds in relation to nest-building, the behavior of the solitary wasp in providing for her offspring which she will never see, the complex relationships among the social insects, and thousands of other cases can be cited to show extremely delicate adaptation of a species to a very specialized mode of life involving at the same time the orientation to the physical and material forces, and to many other species of plants and animals, and to other members of the same species, insuring reproduction.

Among the mammals, which we consider the highest class of vertebrates, the specialization of the class as a whole in relation to reproduction is quite as remarkable as the adaptation found in any single species. Consider for example the mammary glands and the placenta with the development of the young inside the mother's body. We see not merely the modification of skin glands to produce a special kind of secretion, the milk, but the fitness of this secretion for the nourishment of the young and its production at the very time when the offspring is there to use it. We see the native impulses of the young to grasp and suckle at the breast, combined with the readiness of the mother to meet these demands upon her. We see in the placenta an organ made up in part of the tissues of the mother and in part of the tissues of the child. By means of this structure of joint origin, the developing fetus is nourished with materials in the mother's blood, is constantly supplied with oxygen, and is constantly freed of waste material. Yet at no time is there a direct connection between the blood stream of the mother and the blood stream of the fetus.

In some mammals the details of structure and function that distinguish the species show again a remarkable fitness for special conditions of living, for insuring the production of offspring, and for protecting the young. The early naturalists, like the casual observer today, could not but be impressed by these adaptations. And in proportion as one is impressed, he is likely to consider adaptation the central fact in specific differences.

Fitness Never Perfect

A large part of the living activities of many species can be carried on only at the expense of other living things. The early bird may be to a certain extent better adapted than the late bird, but if adaptation were equally good on the part of the worms, the bird would never have anything to eat. We cannot have perfect adaptation both for catching prey and for escaping enemies. We cannot have perfect adaptation for a parasitic worm and for its host. If all plant life were protected against destruction by animals, there could be no animal life except such as lived on plants already dead. The very existence of the multitudes of forms points to a progressive adaptation of life in general, to a progressively changing, even progressively more complex, environment. We must constantly bear in mind the fact that the environment of any species includes not only the physical conditions but also other living things. Every change in physical conditions entails a change in the amount of plant life and in proportions of the various species of plant. This change in turn brings with it a change in the numbers and proportions of animals, which depend upon these various plants for their food.

Perhaps we can see both the relativity of adaptation and the inevitableness of constant change if we consider what happens in a given region with the advance of the seasons. In the spring as the snow melts away, we see very little of green foliage and practically no insects. A careful search will reveal worms, grubs, sow bugs and beetles emerging from the thawing soil. The waters and the ponds appear destitute of inhabitants. From day to day, however, green things and moving animals are added to the picture. It is an evidence of adaptation that caterpillars do not put in their appearance until suitable food has already burst from the buds of the trees. It is a part of this same adaptation, indeed, that the mother butterfly does not begin to lay her eggs until the leaves are already in sight. Still farther back

lies the adaptation that the butterfly does not emerge from her winter sleep until the leaves are ready for her. These details are all tied up with the change of temperature which makes possible the movement of water in the soil, into the roots of the tree, up the stem, and into the expanding buds. It is the same rise in temperature — and liberation of water — that forces the butterfly out of the pupa case and the leaves out of their buds. It is the same rise in temperature that brings the frogs and toads out of their winter sleep and stimulates or releases the millions of seeds to sprout. And the same change in temperature releases myriads of one-celled plants and animals lying dormant in the water.

The Interdependence of Living Things

These many plants and animals that make their shy appearance with the coming on of warmer weather are all interrelated in the sense that they depend upon one another for their existence. The green plants alone are capable of manufacturing usable food from the abundant raw materials — water, carbon dioxid, and the soluble salts of the soil, which are present in natural waters. These plants in turn, beside serving as food for the animals and for those plants like fungi and bacteria which cannot produce their own, depend upon the animals and upon the fungi and bacteria for two essential processes. It is these other organisms that in their metabolism constantly restore to the atmosphere the carbon dioxid which is essential for the life of the green plants. And it is these other organisms that restore constantly to the soil and the water the materials which the green plants build into their bodies and which would eventually be exhausted but for the restoring processes of decay and destruction. It is conceivable that a primitive type of bacterium capable of nourishing itself with the aid of sunlight from the inorganic substances of the ocean might continue to exist over an indefinite period in utter independence of other living things. Such an independent existence, how-

ever, is quite out of the question for the common plants and animals as we know them today. However the situation has come about, they are now both as individuals and as groups completely enmeshed in the lives of one another.

The multiplication of any one species is definitely limited by the existence or absence of other species. As the season advances, there is a daily fluctuation in the proportions of the inhabitants of the soil and of the water. A few cloudy days will diminish the growth of certain plants and reduce the available food for some of the animals. Rapid growth of some seedlings will increase the shade over some square feet of soil and prevent the growth of other plants. Anyone who has been confronted with the weeding of a garden will know how much faster some plants can grow than others and how the growth of some interferes with the growth of others. This is not merely a question of occupying space. It is also a question of modifying the soil chemically either by removing from it or putting into it substances which are effective either to promote or retard the growth of others. As vegetable life increases more and more, animal life also increases, both as to numbers of species and as to numbers of individuals.

Animals come in conflict with one another in various ways. One species may compete with another in utilizing a limited amount of food. Each animal is exposed to the predacious activities of others. The birds seem to have an uncanny knack of finding insects where most of us would never see them. The more birds there are the fewer insects will there be in a given area. Adaptation of birds to see insects is met by counter-adaptation of insects to escape being seen: both cannot be perfect. The frog's eggs eventually become tadpoles and the tadpoles eventually become young frogs, hopping onto the land, where they change their diet. A perfectly adapted frog will capture every insect which comes within several inches of its snout. A perfectly adapted insect will escape every attempt of the frog to capture it. A perfectly adapted bird or snake will capture every frog to-

ward which it strikes. A perfectly adapted frog will escape every attempt of his enemies to capture him. What actually happens is a compromise between the *more or less adequate adaptations* of the numerous individuals of the hundreds of species of plants and animals to be found in a given area.

Changes in Population

Day by day changes in the temperature and in the moisture bring with them changes in the proportions of the various plants and animals. New species appear upon the scene, those that emerge later than the others from the winter's rest, those that push in from neighboring territory. The migrating birds do not all arrive at the same time. And each new arrival changes the environment for those already present. The balance of life is both intricate and delicate. Every change in detail brings with it many changes in other details. The leaves of a plant are destroyed by caterpillars. The plant dies down and becomes food for molds and bacteria. These make possible the rapid increase in the number of various species of small animals, "worms," insects and crustaceans. These in turn make the area favorable for larger animals. At each point adaptation means fitness for a particular situation, which for some species must be rather restricted. Certain insects, for example, will feed only on particular types of plants. Certain fungi will attack only certain kinds of plants.

These daily fluctuations in the actual make-up of the life of a region set the limits for subsequent life. A given area or a given body of water comes to contain a maximum amount of life precisely because of the great variety of forms. Every cranny comes to be occupied by some form. With the coming of colder weather, we see again two kinds of changes in the composition of the flora and fauna. There are changes inherent in the life cycle of the plants and animals; other changes are due directly to the changing temperature, moisture and illumination. The production of seeds by many

plants has had to await the feeding activities of bees and butterflies. The appearance of autumn coloring results from the relative drying of the soil. Many mammals change the texture and the pigment of their fur as the weather becomes colder. Worms and larger creatures burrow deeper into the earth. The nestlings have already learned to fly and with the surviving parents prepare to leave for Florida and points south. Each detail in all of these processes is in a way an adaptation to life. And each adaptive act or structure is limited in its effectiveness by conflicting processes and structures on the part of other living things.

A Struggle for Existence

There are always more mouths to feed than can be supplied by the available food. More blades of grass always push above the soil than can possibly be supplied by the moisture and salts available, to say nothing of standing room. The struggle, however, is for the most part the more immediate one between the individual and changing moisture, heat and light, and the presence of enemies large and small of other species. A change in temperature is in most cases, for a given plant, a more immediate problem that the need for additional food. Fluctuations in external conditions, including the numbers and varieties of other plants and animals, demand continuous adjustment. A plant may conquer the wind by yielding gracefully to its fury or may resist it by building firm buttresses. All life is struggle from the very nature of things, although the struggle is not for the most part of a kind suggested by our own experience with competitive conflicts.

Darwin laid great emphasis upon the fact of individual variations; and it is indeed true that no two individuals are exactly alike. This means of course that at any given moment one individual may be more advantageously situated than another. Further than this, however, is the fact that no individual is exactly the same from moment to moment.

There is not only the continuous change which is associated with growth and development. There is the significant fact that remaining alive means continuous change in response to changing external conditions. It is this plasticity of the individual whereby the response is more or less adequate for meeting the immediate needs that makes possible *adjustment*, or the individual's survival from moment to moment, as distinguished from *adaptation* which we think of as the means whereby the race or the species continues from generation to generation.

These processes of adjustment are not so obvious simply because they are too familiar to be noticed. When the erect stem of a plant is bent over and kept in a horizontal or inclined position, the tip will gradually change the direction of its growth and acquire a vertical posture. A reduction in the illumination will bring about an acceleration in the growth of a plant's axis. A one-sided illumination will in most green plants bring about a modification in the direction of growth, so that the tip and the upper surfaces of the leaves come to incline toward the source of light. A reduction in the amount of moisture will lead in many plants to a thickening of the cuticle or to the formation of hairy epidermis or to the shortening of the main axis. These and many other responses of plants are so well suited to the individual's need for light and for moisture that we cannot but be impressed by their apparent purposefulness.

Adjustment a Continuous Process

All living things respond more or less adequately to these fluctuations in the immediate surroundings — or they succumb. In our body we find numberless examples of such fluctuating variations from moment to moment. We say, for example, that the normal temperature of the human body is 98.6° F. But this normal means merely the temperature found most frequently among large numbers of people under ordinary conditions. It leaves a considerable range of in-

dividual variation, so that some of us are consistently warmer or cooler than the normal. Moreover, in the case of any particular individual, the temperature is constantly fluctuating with the variations in external and internal conditions. It is not everybody who can get into a fever heat through trivial aggravation, but everybody does raise the temperature of his blood through muscular exertion or emotional strain.

The output of heat incidental to increased activity of all sorts would become a source of injury to the living matter of the body if the mechanism for maintaining a fairly uniform temperature were not as effective as it is. The increased consumption of oxygen made necessary by increased activity is made possible by accelerated breathing and heartbeat. Everybody knows that running around the block results in more rapid breathing and more vigorous heart action and more copious perspiration. We commonly assume that the *need* for more oxygen and for the more rapid removal of the carbon dioxid and for preventing an excessive increase in temperature somehow brings about these suitable modifications in the behavior of our organs. A lowering of the temperature somehow leads to a closing of the pores, and a reduction of perspiration. Variations in the composition of our food bring about variations in the proportions and quantities of the various juices that take part in digestion.

The invasion of the body by foreign bodies such as bacteria produces highly specialized reactions on the part of the white corpuscles of the blood and probably also on the part of other tissues (see page 61). The automatic reflexes in which the nervous system participates are commonly recognized as purposeful. The contraction of the pupil of the eye with increasing illumination, the blinking of the eyelids on the approach of minute particles, the withdrawing of a limb in response to injury, the increased flow of saliva in response to stimulation of the taste organs of the mouth and so on, are familiar examples of adjustive reactions. The internal organs, as well as the externally visible structures, are also constantly changing in many details as part of the process

of maintaining the unity of the organism in the presence of constantly changing conditions. It is these minor actions and reactions that in their totality constitute the essential and continuous struggle for existence.

It is well to keep in mind that in so far as a plant or animal continues to remain alive this struggle is successful. On the other hand, the adjustments in detail can never be altogether perfect. Certain of the mechanisms may be relied upon to operate automatically and effectively, but in so far as new situations arise, there must be in the life of every individual a relative failure in one detail or another. This is illustrated by the reactions of higher animals to a change in diet. While it is true, for example, that the animal's choice of food is adequately guided by its "instincts," this guide is never perfect. In the case of many birds and mammals the individual learns by trial and error what food is acceptable to the taste and it is by trial and error that many of them discover that some food is acceptable to the stomach and the blood. If the adaptation at this point were quite perfect it would never be possible to poison an animal. The individual human being learns to accept new kinds of food not only as a matter of taste, but also as a matter of adequate management by the stomach and intestines. Acute indigestion would be impossible in an organism perfectly adapted to its environment.

Kinds of Variation

We are told that with some attention one can learn to know individual pigs or geese or chickens apart just as we know many people "by name." Most of us are unable to analyze the make-up even of human beings to say just what is distinctive about each individual. We commonly recognize differences in size or stature, in proportion, in the shape of the features, differences in color of hair and skin and eyes. Most of these differences are measurable, as are many others that we observe in common plants and animals. We can

measure the length of hair in the wool of sheep, or the length of fibre in cotton, or the thickness of hide in cattle. Physical measurements can be combined to give us proportions, as the relative length and width of the head, the ratio of sitting height to standing height, or of girth to length.

In all of such measurable characters we find individuals differ, and they differ in a mathematically constant manner. In a given population the individuals may vary as much as ten or twelve inches in height, although there is in every population a tendency for the various statures to cluster around a central point. The number of individuals of a given stature constantly diminishes as this stature departs from the mean. This was first worked out by a Belgian mathematician, Quetelet, in 1845. One does not need to be a mathematician, however, to follow the argument. These measurements and calculations merely present in a more precise form what every person of ordinary intelligence already knows, namely, that there are more people of about the so-called average height than there are very tall or very short people. It is exactly what we mean when we say that a person is exceptionally tall or exceptionally short. We mean by exceptional relatively rare, not common or frequent. The mathematical formula shows us, however, that the distribution of such measurements follows a regular course, so that while it is impossible to tell in advance how tall a particular person is going to be, we can tell with a remarkable degree of accuracy what proportions of individuals we will find for any given stature (Fig. 38). It is this principle that enables the quartermaster or the manufacturer to stock up shirts or shoes without danger of running short on some sizes and of having a surplus of others.

The distribution of variations according to this so-called chance curve, or the law of probability, is found to hold for many different kinds of measurable qualities. If we adopt an arbitrary scale for measuring degrees of pigmentation in the hair, we shall find variation in hair color to follow the same distribution. If we count parts that are variable in

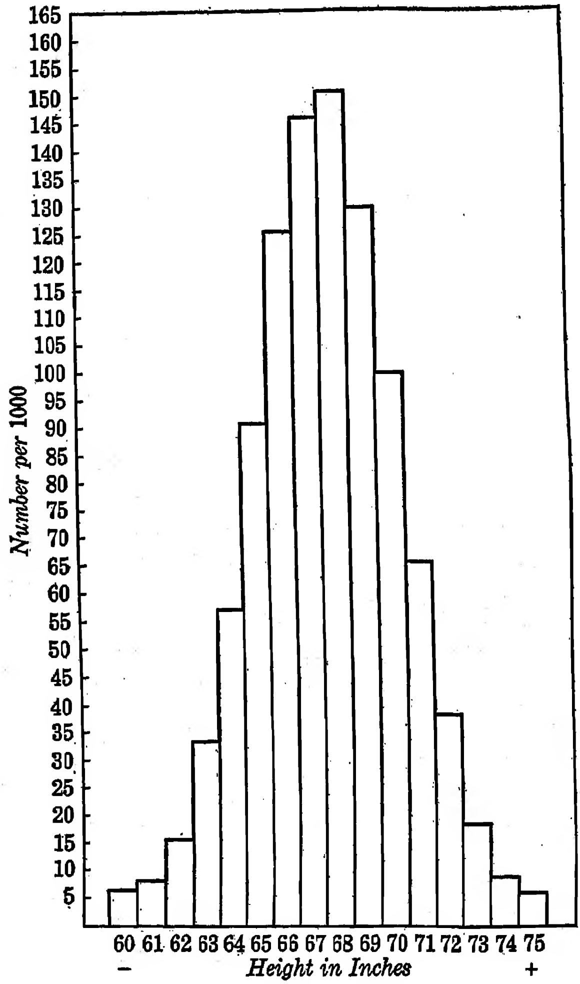


FIG. 38. DISTRIBUTION OF STATURE IN A POPULATION

The first million men in the American draft for the World War showed varying numbers in the different stature-groups classed in one-inch intervals, as shown in this diagram. Any large number of men taken from the population at random would show a similar distribution as to stature.

numbers, such as stamens in roses, or ray florets in daisies, or the number of segments in a worm or the number of veins on a leaf, we shall find a similar distribution. This statement of individual variation does not mean that no two individuals have the same number of variable parts, but that within certain limits an individual may have any given number.

Physiological Variation

No two cows will give precisely the same amount of milk day by day, and of two quarts of milk obtained from two different cows, the proportion of fat will be different. Muscular strength varies among individuals. In a flock of hens some will lay more eggs during the season than others. The amount of sugar to be obtained from a pound of cane or a pound of beet will vary from plant to plant. In Persia it has been known for centuries that some horses can run faster than others. In so far as we can measure these characters they also follow the curve of probability.

Parallel to such variations among individuals are differences in immunity and susceptibility to various infections, the ability to recover from injury or fatigue, in the capacity to digest food in general or particular materials. There are individual variations in the speed of response to stimulation, in the ability to discriminate fine shades of color or fine shades of pitch or of loudness. While we cannot measure such differences as readily as we can the more obvious physical qualities, they seem to be distributed in pretty much the same way.

The indications are that many emotional or temperamental differences noted among human beings are also essentially of the same kind. Some of them seem to be correlated with variations in the amounts or proportions of specialized substances produced in the body, such as the insulin of the pancreas, the secretions of the thyroid gland, of the adrenals, and so on. It is conceivable also that the commonly accepted intellectual differences are due to com-

binations of structural variations of the brain and nervous system, of the sense organs, and of chemical or functional differences of the various tissues, including the so-called ductless glands.

We may say then that in general there are individual variations within a given group of plants or animals both in respect to the chemical and functional characteristics and in respect to the physical and mechanical characteristics. In any given set of observations, we are likely to find a continuity of characteristics from one extreme to the other with a tendency for more and more individuals to cluster around the mode or typical measurement. Variations of this type have accordingly been designated as *continuous* variations, or fluctuations. With regard to our idea of species, the assumption has been made that individual variations are quite normal so long as they confine themselves to these limits. The concept of fixity of species assumes that while there is a great deal of fluctuation in all directions (that is to say, with respect to every character), the individual of a given species never transcends these limits. The problem of evolution is to consider (1) whether as a matter of fact any individuals of known ancestry do or do not ever transcend these supposed limits of fluctuation, and (2) whether there is any intergradation between one supposed species and another.

Sources of Variation

We do not know in general what causes one individual to differ from another of the same species or of the same parentage. Many possibilities suggest themselves. We may think of the plastic organism being forced in the course of its development to assume one character or another by the external conditions. The distortions of the human figure imposed by various occupations might be an example of such a process. We might suppose that the response of the organism to varying stimulations would bring about diverging end results. Children exposed to sunlight become

darker in appearance than those who are shielded from the stimulus of the ultra-violet rays.

Another possible source of variation is conceivably present within the individual as an inherent tendency to depart from the ancestral pattern. There is some evidence that during the age of the giant reptiles there was such a tendency toward the elaboration of armors and horns, although we cannot of course speak in detail of what happened as between one group of individuals and their immediate offspring.

Finally it is conceivable that variations are brought about by the action of the environment not upon the developing organism itself but upon the germ cells in the parent. There is some recent experimental evidence that such modifications are actually possible.

Dr. W. L. Tower, an American biologist, exposed potato beetles during the early stages of their development to extreme conditions of moisture and temperature, with the result that the adult beetle showed distinct deviations from the parental type in color and pattern. Succeeding generations raised from these beetles, however, under normal conditions, looked like the common variety, and did not show any effect of the violent treatment to which their progenitors had been subjected. That is to say, in these insects as in others the conditions of development influenced the adult appearance, but the effect of the environmental forces was not carried on into the following generations.

In another series of experiments, Tower subjected the young beetles to extremes of temperature and moisture at the time when the ovaries and spermaries were being formed. In these cases the adult beetles appeared perfectly normal. The progeny of these beetles, however, raised under normal conditions, presented several distinct types which could be related to the conditions to which the parents had been exposed. Still more striking is the fact that these changes in color and pattern were then reproduced in succeeding generations, indicating that a germinal change had taken place under the action of the environmental forces. These results

have not been confirmed, and it is possible that the mutations, or heritable traits departing from ancestral types, happened to appear in the course of the experiments and were really unrelated to the artificial conditions imposed upon the developing parental beetles.

More recently, Professor H. J. Muller, of the University of Texas, has succeeded in inducing mutations in fruit flies by exposing the insects to graded doses of radium before maturity. The adult individuals thus treated did not show the effects of the radiation; but among their offspring there appeared large numbers of individuals with one or more departures from the standard pattern of the wild red-eyed fruit fly. There were several distinct alterations of the wings, of the eyes, of the abdomen and of other parts — over one hundred of the same kinds of sports as had previously appeared spontaneously in the cultures of Dr. Thomas H. Morgan and other students. The radium had apparently done something to the germ cells of the male and female flies, something that influenced the development of subsequent generations and not merely the immediate progeny. The aberrant traits were all heritable (see page 272). The effects of the radium seem to be no different in kind from those of other forces normally acting upon the species; but the radiations seem to accelerate the normal processes several hundred times.

Multiple Influences

The distribution of variations about a mean or "average point" suggests the operation of many factors. We can see this if we imagine that each individual in the course of attaining his full stature, for example, can be influenced by only two factors, with the chances even of meeting either, neither or both. There would accordingly be four classes of such individuals: the very tall ones, that had met with the favorable factor; the very short ones that had met with the unfavorable factor; the medium-sized individuals that

had been influenced by neither factor; and the medium-sized individuals in which the two factors had neutralized each other. If the two latter had the same appearance, the distribution of forms would be therefore 25 per cent short, 50 per cent medium, and 25 per cent tall.

If we imagine four factors to be at work, two favorable and two unfavorable, the general course of distribution would be similar, but the number of classes would be five. In such a population, 37.5 per cent would be of medium size; and there would be an equal proportion of extremely tall and extremely short amounting to 6.25 per cent each; and 25 per cent would be considered medium-tall, and 25 per cent would be considered medium-short. For every one in which both favorable factors had operated there would be another one in which the two unfavorable factors had exerted their influence. And for each one of these there would be four in which the two favorable factors met one unfavorable factor, and an equal number in which two unfavorable factors were in part neutralized by one favorable factor; and there would be six individuals in which the favorable factors either neutralized the unfavorable ones or in which neither of these supposed influences operated.

When the number of factors is increased to ten, for each individual that had all of the influences in his favor there would be ten with one favorable factor replaced by an unfavorable one, and 120 in which there had been seven favorable and three unfavorable factors at work, while in 250 cases the favorable and unfavorable factors counteracted each other.

The mathematician can thus find from the distribution of types of variation mentioned that a very large number of factors must be at work, some making for greater growth, or for more pigment, or for more milk production, and so on, and some factors working in opposite directions.

The ordinary fluctuations that we find in any group of plants or animals would seem from these considerations to result from slight variations in the conditions that influenced

growth and development. Just as one cow may yield more milk on some days than on others because of variations in nutrition, one cow may yield more milk than another cow, or one acre of corn may grow taller than another acre of corn, because conditions are more favorable in one case than in the other (Fig. 39). We know from ordinary experience that external conditions do influence growth and develop-

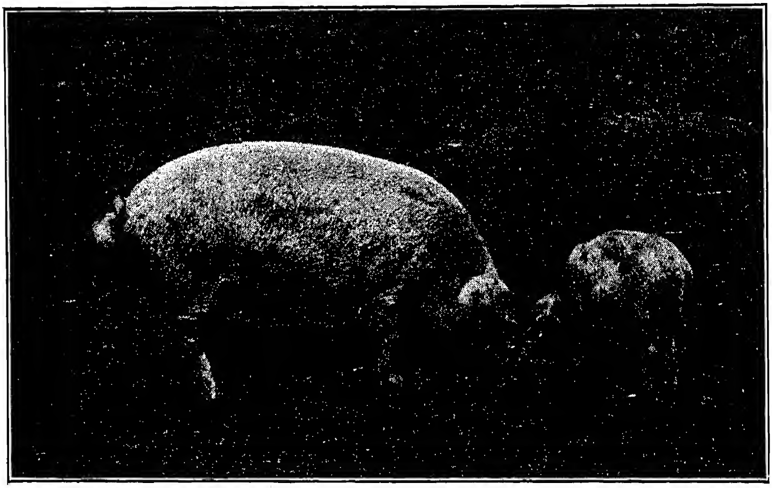


FIG. 39. NATURE AND NURTURE BOTH

These two pigs are of the same breed and of the same age, and both were supplied abundant food. The smaller one lived on a soil infested with round-worms and became infected. Photograph by U. S. Bureau of Animal Industry.

ment, and to that extent the variations found among individuals may be ascribed definitely to varying environmental influences; and this conclusion is supported by experimental evidence.

Influence of Environment

We have already seen that the life of an individual plant or animal is influenced from day to day, we might even say from moment to moment, by fluctuations in external conditions. These external conditions, from the very nature of their fluctuations, work sometimes favorably and some-

times unfavorably to the growth or development of a particular part or function. There is therefore maintained by the species the observed tendency to cluster around its typical or modal form. It is only rarely that conditons continue for a long period altogether favorable or altogether unfavorable.

Both by direct observation and by experiment we can

FIG. 40. INFLUENCE OF ENVIRONMENT UPON PLANTS

Two plants of *Gaura parviflora*, *a* and *b*, grown respectively in shade and in sunshine Two forms of *Solidago*, *c*, the species *oreophila* and *d*, the alpine form of the same, *decumbens*, dwarfed through low temperature and excessive loss of water on account of the low atmospheric pressure at high altitudes After Clement

find that prolonged exposure to extreme conditions does result in a considerable modification of the development. Experimentally a plant may be split into two parts and one grown at a high elevation and another in the valley: the end results are strikingly different individuals (Fig. 40). One half of a plant may be submerged in water while the other is allowed to root into the soil and grow into the air. Again the ensuing individuals are strikingly different in their structure, appearance and behavior, although strictly speaking

we have in both cases portions of the same individual living in different environments. Indeed we can leave a plant growing in the soil and bend a single branch into the water and see it there assume an appearance characteristic of a water plant, while the rest of the same individual has broad leaves characteristic of an air dweller.

FIG. 41. CLIMATIC VARIATION IN COLOR AND SIZE OF SONG SPARROW

The typical form is the Eastern song sparrow, *Melospiza melodia*, 7. 1 Aleutian, *M tanaka;* 2, Sooty, *M rufina;* 3, Heermann's, *M heermanni;* 4, Mountain, *M. montana,* 5, Desert, *M. melodia fallax,* 6, Mexican, *M Mexicana* From photograph of mounted specimens, courtesy American Museum of Natural History

It is a matter of common observation that a group of plants or animals occupying a very large area is frequently made up of sub-groups that show distinct regional variations (see Fig. 41). A wild pigeon of the genus *Scardafella* shows a fairly constant type of plumage in North and Central America. Farther south toward the tropics there are several

darker forms which are rather distinct in Brazil and Venezuela and in Honduras, and have been given specific names accordingly. By means of experiments, it was possible to show that the pigmentation of these birds is directly influenced by the moisture of the atmosphere. By controlling the moisture, it is possible to develop any one of these types.

Among the divergent types of fruit flies in Morgan's cultures was one in which the abdomen was misshapen. When a culture of these flies is allowed to develop in a relatively dry atmosphere the abdomen appears in every way normal. A batch of eggs from a given mother may be divided, one part being placed in a moist atmosphere and the other in a relatively dry atmosphere, with the result that the former batch will show the abnormal abdomen while the latter will appear normal (Fig. 42).

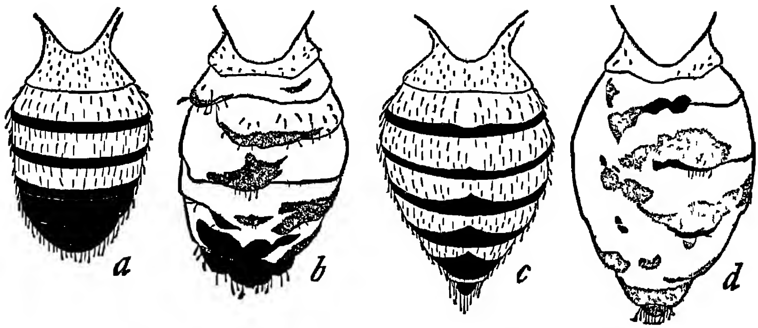


FIG. 42. ABNORMAL ABDOMEN IN FRUIT FLY

A race of flies has appeared in the experimental study of heredity, with a distinctly mis-shapen abdomen Normal and abnormal male, *a* and *b*, normal and abnormal female, *c* and *d* This strain can be raised so that the abdomen will appear normal or abnormal, as conditions of nutrition are modified, whereas the wild strain will develop individuals with normal abdomen under all conditions. After Morgan, The Physical Basis of Heredity, published by J B Lippincott Company

These various modifications show the more or less direct influences of the environment, although they are also in many details adaptive responses to the environment. A lowered temperature results in stunting the growth of a plant. This we can find through experiment to be a purely physico-chemical result. A lowered temperature will in

many mammals and birds bring about a modification of the pigmentation. Among the Chinese primroses are two varieties which at ordinary temperatures produce respectively red flowers and white flowers. When the red flower variety is grown at a higher temperature it produces white flowers. The other strain produces only white flowers at any temperature in which it will grow at all. Among the hundreds of freak fruit flies which Morgan has found in the course of his studies in heredity is one variety which appears normal

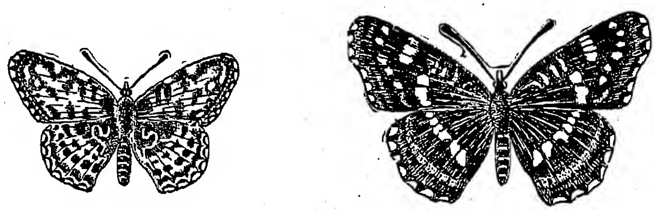


FIG. 43. EFFECT OF TEMPERATURE ON DEVELOPMENT

In the butterfly *Vanessa levana prorsa* the two broods have distinct patterns. By keeping the eggs, larvæ, and pupæ of the spring brood at a low temperature, it has been possible to make the imagos appear in the fall with exactly the same coloring as the spring brood. This showed that the spring form differs from the summer form because of the influence of the temperature. From Gruenberg, Elementary Biology, published by Ginn & Company.

if grown at high temperatures but produces supernumerary legs if raised in low temperatures. The exact mechanism at work here is not known, but is also probably a direct action of the temperature upon the physical and chemical processes involved.

In many flatfish which are typically pigmented on the upper surface and white on the under surface, it has been shown experimentally that the pigmentation is a direct response to illumination. It is possible to raise flatfish with the upper surface white and the under surface speckled by arranging mirrors in an aquarium so that the fish are illuminated from below. In the case of many butterflies the temperature to which the larvæ or caterpillars are exposed will determine the pigmentation of the adult (Fig. 43). In some of these modifications brought about by factors in the environment there would seem to be an adaptive value for the

individual. In other cases, however, the modification seems to bear no relation to the welfare of the organism.

Modification of Development

Many of the influences of environment are familiar enough since they leave the individuals, however they may differ from the "type," still within the boundaries of our

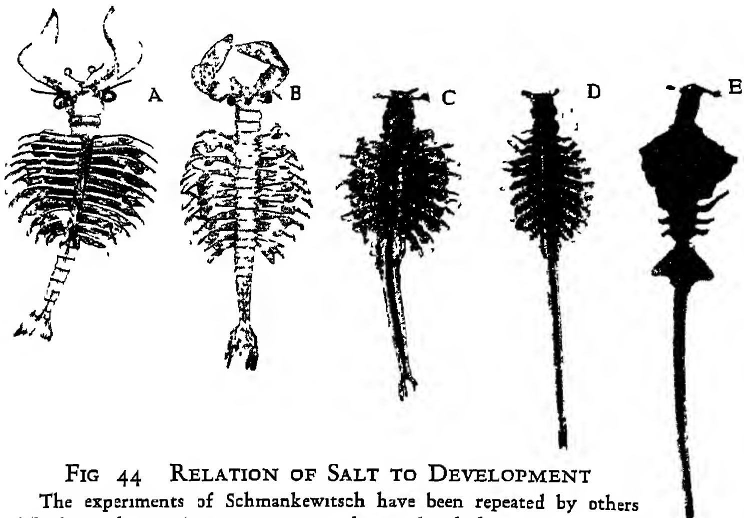


FIG 44 RELATION OF SALT TO DEVELOPMENT

The experiments of Schmankewitsch have been repeated by others The brine-shrimp *Artemia arietina,* C, lives in brackish water By diluting the water slowly modifications are brought about in the appearance of the animal, so that in a few generations it seems to be a totally different animal — B, A, by concentrating the water modifications are brought about in an opposite direction — D, E A and B have been known as species *of Branchipus* The changes can be reversed, and include differences in the proportions of the body and tail (abdomen), the degree of branching and numbers of bristles on the tail, the size of the head organs, and the mode of reproduction After Abonyi

conception of species. When an excess of iron in the soil makes the hydrangea bear bluish flowers instead of the usual white blossoms, the divergence does not raise the question of new species. Diluting sea water with fresh water, Schmankewitsch was able to influence the development of certain water fleas, so that they took on the appearance of what had been considered a totally different species; and he was able to reverse the process by increasing the concentration of the brackish water (Fig. 44).

Dr. Stockard modified the chemical composition of sea water in which the eggs of the small minnow *Fundulus* were hatching by increasing the proportion of magnesium salts.

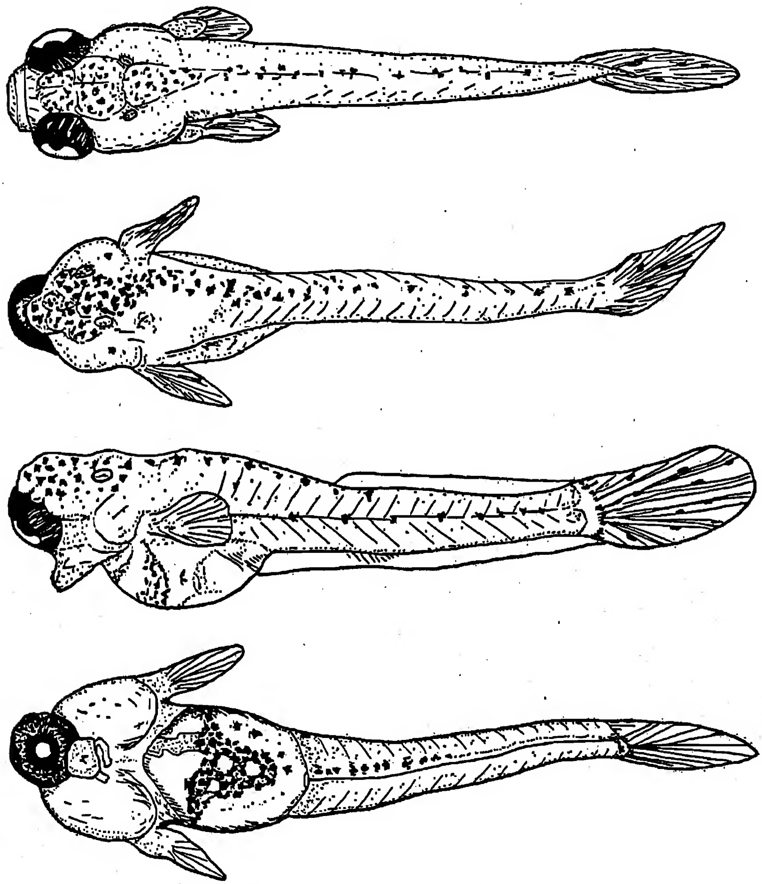


FIG. 45. CHEMICAL MODIFICATION OF DEVELOPMENT

These cyclopean minnows are strikingly different in appearance from the two-eyed individuals with which we are familiar (two-eyed larva at top). The development of eggs from a given batch into one type or the other can be controlled by regulating the proportion of magnesium in the sea water. After Stockard.

When the ratio of magnesium to sodium exceeds a certain point, the young fish hatched out with a single eye in the middle of the forehead instead of the usual two eyes on the sides (Fig. 45).

It has long been known that among the honey bees the queen mother lays two kinds of eggs: the unfertilized eggs which develop into drones or males, and the fertilized eggs which develop into workers. These workers are females in which the reproductive organs are not fully developed. On the loss or death of the queen, a larva which would normally develop into a worker is made to develop into a fertile female by increasing the amount, and probably also modifying the character, of the nourishment supplied. The fertile female is certainly different from the unfertile worker; and this difference results apparently from a difference in nutrition.

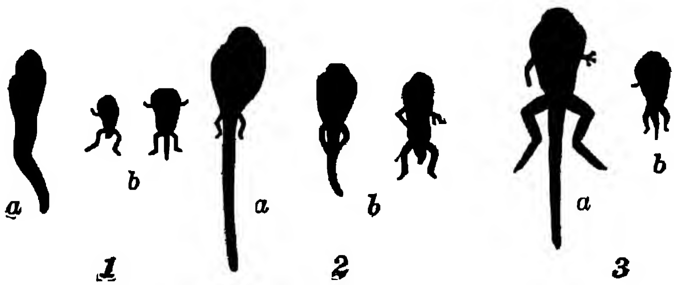


FIG 46. INFLUENCE OF THYROID ON DEVELOPMENT

In each series, *b* shows the tadpoles that had been fed on thyroid much more advanced in development, although smaller, than the controls, *a*. The control animal in *1* was fed on plant food, in *2* on muscle, in *3* on adrenal All full size The animals that were fed on thyroid *developed* very rapidly, passing through the metamorphosis into the adult form while still very small Those fed upon thymus (not shown here) *grew* very rapidly but failed to undergo their metamorphosis even after they had exceeded the size of their parents (After Gudernatsch.) From Gruenberg, Elementary Biology, published by Ginn & Company.

Gudernatsch divided the fertilized eggs of a frog into several sets of two batches each. When the tadpoles appeared he supplied those in one batch with a special diet prepared from the thyroid gland of a mammal, and he fed the others with various foods. The thyroid gland has in recent times become more familiar to us as the source of disturbances related to goiter, and of emotional manifestations related to increased metabolism. Now Gudernatsch's tadpoles, who presumably knew nothing about modern research into duct-

less glands, manifested striking peculiarities in their development (Fig. 46). These results have been verified and extended and show very definitely that the character of the development is related to the characters of the metabolism, that this in turn is not merely a question of what is inherited but also a question of material income and of chemical actions and reactions. In the examples given, the individual is taken for granted, the modifications operating at some point after the fertilized egg has started its development.

There is unmistakable evidence that the environment does in many ways bring about variations. Indeed there are many people who question the value of any effort to improve conditions of living, whether for human beings or for cattle, unless there is some hope that the recognized effects of such improvement will in some way carry over to subsequent generations and render eventually further effort unnecessary. This problem is closely tied up with the whole question of what is and what is not inherited. While the tendency among the professional biologists is to question the heritability of any modification, a large part of the difficulty lies in our terminology, or rather in recognizing clearly what is a modification and what is a normal manifestation of inherent capacity.

Use and Disuse

From the point of view of evolution it is important to ask further whether any of the modifications brought about either by the direct action of the environment upon the organism, or by the response of the organism to the environment, are ever transmitted to the offspring. We are all familiar with the effects of use and disuse. Exercise leads to growth; the blacksmith's arms are stronger than the priest's. Primitive people who eat harsh food have in general better teeth and larger jaws than most of our own neighbors. Practice increases skill. We know also that on the other hand

disuse leads to atrophy. Inhabitants of rookeries become pale. Sedentary occupations are associated with flabby muscles and sluggish intestines. Lamarck assumed that these effects of use and disuse became in time permanent characteristics of the race. There is a tendency in general for educators and sociologists to take for granted the cumulative effect of environment in modifying the type. Those who are more familiar with plants and animals as they naturally live and reproduce from generation to generation are inclined to be more skeptical about the transmission of traits acquired in the lifetime of the individual as a result of external influence, or of use or disuse.

Preserving Variations

Luther Burbank produced dozens of "improved" varieties. Many of these have become well established commercial strains. We are all today enjoying potatoes (unless we are dieting) and berries and flowers and garden truck and grains that did not exist two generations ago, as a result of the work done by Burbank and others.

Whether we call these new strains merely varieties or new species may be a purely academic question. In whatever detail they are superior to the ancestral strain, we have shared in the benefits. From a pragmatic point of view the novelties are sufficiently distinct to warrant separate names, not only for the benefit of the dealer or promoter or catalogue maker, but for the benefit of every ultimate consumer. The manufacturer, at any rate, knows whether he prefers cotton with long staple or with short staple. The farmer knows whether he prefers a wheat that will withstand frost, he knows the advantage of a grain that will not succumb to the rust. Some people at least know what kind of melon they prefer or what kind of apple or corn or grape. Some people even pretend to know one kind of tobacco from another.

The improvers of the plants have contributed a great deal of material value. They have added to the enjoyment

of life and they have taught us a great deal about the nature of living things. But they have in some respects evaded our question regarding species. When a seedless orange appears upon a respectable orange tree it is necessary merely to preserve the twig or branch that bore the freak, and to encourage it to bear more. It is of course impossible to plant seeds for the purpose of raising more seedless orange trees. It is possible, however, to make grafts and cuttings. With many species of plants it is possible to get more individuals by having twigs or branches continue their growth after being detached from the parent stock. Similarly it is possible to propagate many plant varieties by means of bulbs, tubers, root stocks and other vegetative parts. Thus we can preserve the qualities we desire in a constant succession of new individuals. The fact that these plants can be propagated by vegetative means is relied upon for the practical purpose of getting more of the desired kinds; but it leaves us in the lurch if we are intent upon answering the question whether one of these deviates is a "true species," for it avoids the test of consistent reproduction.

There are other plants that reproduce only by seeds — that is, by a true sexual process. From these we can tell whether the qualities that concern us, the new qualities that characterize the strain, enter into germinal continuity. We may consider the hundreds of varieties of wheat and corn and other cereals, of beans and peas and vetches and lentils, of cotton and tomatoes, and of annuals grown for their flowers. These varieties or strains breed true, yielding constantly new individuals with the characteristics for which they were selected in the first place.

In many cases these new strains are the result of hybridizing or crossing of two strains. This is only to say, however, that

(1) there are varieties to be crossed;

(2) new strains can be produced by crossing; and

(3) hybridizing may result in the production of stable and self-sustaining varieties.

New Creations

We have learned in recent times a great deal about the effects of hybridizing and the reasons for the apparent instability of hybrid types (see page 254). A part of this understanding enables us at least to anticipate the behavior of seemingly new plant or animal forms which are the result of hybridization. They enable us with greater certainty to establish pure lines in which a desired character — for example the absence of horns in cattle — may be assured in successive generations. We have then at hand a means of controlling plant and animal breeding so that not only can new qualities that present themselves be preserved but *new combinations of qualities can be produced to order.*

To say that variation may result from hybridizing is to point to one method by which variation is brought about: it does not affect the significance of the variation as a possible step in evolution. It does raise again, however, the question of the traditional assumption that distinct species are sterile when mated. We have seen (page 68) that animals of distinct species, even of distinct genera, may be made to breed together. The same is true of many distinct types of plants. On the other hand, cultivated varieties of what are commonly accepted to be the *same species* are often sterile when mated.

When it comes to the variations observed among domesticated animals and the establishment of new breeds by selection and segregation, we are not distracted by the question of propagation. These animals all reproduce sexually and we are not long left in doubt whether given characteristics reproduce themselves in succeeding generations. We are familiar with *new* breeds of dogs and cats, cows and horses, sheep and pigs, poultry and pigeons, to say nothing of the numerous breeds of fancy or pet animals that have no direct economic importance. These indicate that, starting with variations, it is possible to establish numerous strains from a common ancestry. Animals that differ more from each other

than many wild types which are universally recognized as distinct species are derived before our eyes from a common stock.

The Effectiveness of Selection

Objection has been raised to the analogy between artificial selection and the natural origin of species on several grounds. Whether natural selection, using Darwin's term, is or is not actually effective, and whether segregation is necessary to prevent the swamping of the variants by the preponderance of conforming individuals, may be left for later discussion. More immediate considerations are these facts:

(1) Domesticated breeds do not remain constant unless there is repeated selection, and they tend to revert or "throw back" to ancestral types; and

(2) Domesticated animals and plants cannot maintain themselves unless protected against the exigencies of weather, enemies and disease — they cannot look after themselves in competition with "real" species.

The first of these objections had considerable weight until experimental methods forced us, since the beginning of the present century, to distinguish between strains that, for various reasons, *appear* to be distinct, and strains that carry their distinct capacities, so to say, concealed in the germ plasm. About 1903 Villem Johannsen, the Danish botanist, conducted very extensive experiments in the course of which he made some significant discoveries. Selecting a variety of the common bean which is self-pollinating, he carried through successive generations a number of "pure lines." Taking a single bean as the progenitor of a line and saving the seeds from the ensuing plant and growing again from these, he was able in the course of several generations to obtain a population of the same ancestry. In such a pure line the smallest seed and the largest seed gave rise in subsequent generations to variable populations, but the offspring of the largest seed varied around the same mode as did the offspring of the smaller seed. There was no tendency in the course of

generations of breeding for the smallest seeds to give rise to offspring with small seeds, or for the large seeds to yield offspring with consistently large seeds. This would indicate that the systematic selection of seeds in this manner does not bring about a distinct variety of a consistently diverging type.

In another series of experiment, however, Johannsen took from a mixed lot of seeds, which to all outward appearances might have been a sample from one variety, and produced by means of pure line breeding some nineteen distinct types. In these experiments the character upon which attention was fixed was the weight of the seed. A type was considered established by a consistent fluctuation of seed weights around a distinct mode (see Fig. 89). That is to say, it was impossible from mere inspection to tell whether a given seed belonged to one or another of these pure line types. It was possible, however, by planting and raising a new crop and then measuring the seeds, to show that each line preserved consistently its own range of variation in seed size.

Genotype and Phenotype

As a result of these experiments, Johannsen suggested the importance of distinguishing between a type which is such in appearance only and may include individuals of varied hereditary capacity, and a type which is fairly uniform from the hereditary point of view. To the former he gave the name *phenotype;* and to the latter the name *genotype.* In a mixed population there will be many distinct strains so far as hereditary capacity is concerned but appearing to casual inspection quite indistinguishable. For example, we may find two men of the same stature, one of whom is a short representative of a rather tall stock, whereas the other is a tall representative of a short stock. Without knowing anything of their families we should class them as having the same character or quality — that is the same phenotype, say a stature of 68 inches. From a knowledge of their ancestry or their offspring we might recognize them as belong-

ing to different genotypes (so far as concerns the one character, stature).

If we select plants or animals because of some particular quality that we value we may succeed in establishing a pure line that reproduces the quality in question consistently; or we may fail after repeated selection to get a stable population. It all depends on whether in selecting we are dealing with a phenotype or a genotype.

Jennings in this country experimented with a one-celled slipper-animalcule, the paramecium. This lives in stagnant waters and is easily cultivated in hay infusions, where it feeds upon bacteria. It multiplies rapidly by simple cell-division, each individual giving rise to two. Starting with a single paramecium in a dish, Jennings allowed the animal to multiply until there was a colony of a large number of individuals. In this colony there was a relatively wide range in size (see Fig. 92). Some of the smallest were taken out and allowed to multiply in one series of dishes. Similarly, some of the largest were separated and allowed to multiply in another culture. After many generations Jennings found that the individual variation among the offspring of the smallest was exactly the same as the variation among the offspring of the largest. Selection produced no effect whatever. On the other hand, if several paramecia were picked out of a "wild" lot or mixed population, it was possible to get, by selecting the smallest in one direction and the largest in another direction, paramecium populations that were consistently small in the one case and consistently large in the other case (although of course there was the individual variation in each group). That is, each series had a distinct modal dimension.

Negative Results of Selection

Other controlled experiments in which the effort has been made to establish pure strains by selecting for a particular quality, such as pigment pattern or egg production,

have always yielded negative results. There have been, to be sure, both traditions and systematic experiments among breeders and horticulturists that seem to justify the assumption that consistent selection will result in improvements. The success of artificial selection was in fact the foundation of Darwin's theory.

Some thirty years ago an experiment was started at the University of Illinois designed to modify the proportion of protein in corn grain by selection. Starting with a grain in which the average amount of protein was about 11 per cent, they produced two extreme strains so that in the course of twenty years of selection, one had 14½ per cent protein and the other just half as much. At the present time, however, the results of this experiment would be interpreted as indicating something other than mere selection. It is now apparent that while the experimenters were not aware of doing more than segregating extreme *phenotypes,* they were actually segregating *genotypes,* just as Johannsen had done with his beans.

The selection of variants generation after generation does *not* modify the hereditary capacity of strains. To this extent, therefore, our experimental evidences fail to support the theory that new varieties (and *a fortiori,* new species) arise by consistent selection for a particular character. Indeed, if we had no further evidence than experiments of the kind mentioned, we might be strengthened in our belief that species are actually fixed entities, however much intergrading there may be between one species and another. We could accept these intergrades as merely phenotypical overlappings of one species and another with the certainty that each individual, however much he may resemble an individual of another species, belongs truly and permanently to its own kind. But the *kind* in this case does not correspond to what we commonly think of as a species, but to a hereditary strain which manifests the character in question. The ordinary species may have in its composition an indefinite number of genotypes.

Mutations

In 1791 there appeared on a Massachusetts farm a freak sheep which was remarkable for his very short legs and relatively long body. The owner kept the ram and subsequently established an extensive flock of these short-legged animals, not so much for their beauty as for the ease with which they were kept within bounds. They were not good fence jumpers. In the forties of the last century this Ancon breed disappeared. In 1919 an animal resembling our record

FIG. 47. THE ANCON TYPE OF SHEEP

There are no descendants of the famous Ancon ram that appeared in Massachusetts in 1791. The animal shown in the picture has the short legs and long body of that sport, but it was born from apparently normal parents in Norway, in 1919. Photograph by Director of the Jonsberg Agricultural School, Norway From Gruenberg, Biology and Human Life, published by Ginn & Company

of the Ancon sheep was born on a farm in Norway of apparently normal parents. She gave birth to one daughter of the same type (Fig. 47). The other descendants were normal. The well established merino sheep is derived from a single mutation that appeared in 1828.

In former times the appearance of an individual that

was markedly different from the parental type was looked upon as a freak and was called by breeders a "sport." Darwin knew of the existence of these sports and indeed described some in his books. He did not, however, take them seriously as possible sources of new breeds or species.

In 1886 Hugo de Vries gathered the seeds from some evening primroses which were growing in vacant lots. These had apparently escaped from cultivation in Dutch gardens, since the plants are natives of North America. From these seeds he obtained over 15,000 new plants, among which were five extremely small individuals and five others with extremely broad leaves (Fig. 48). These two varieties differed not only from each other and from the parent plants that supplied the seeds but also from other known varieties of the genus. These two sports were cultivated separately, but identical forms appeared spontaneously in successive generations grown from the seeds of the parent type. Ten years later, and after four generations of seeds had been grown from the original stock, there appeared seven new varieties including the dwarf and the broad-leaf of the first experiments. These new types showed very distinct characteristics such as oblong leaves, reddish veins, pale flowers, gigantic stalk, and so on. It was possible by means of careful breeding to preserve new qualities and eventually to recombine one with another and with the contrasting characters of the parent type in accordance with the so-called Mendelian principles of heredity. In the thirty years that have elapsed mutations have been observed in many plants and animals, both wild and domestic.

The most intensive studies of the principles of genetics have been carried on in the Biological Laboratory at Columbia University under Professor Thomas H. Morgan, now at the California Institute of Technology. His work with the fruit fly *Drosophila* revealed literally hundreds of details wherein this comparatively simple organism may differ as between one individual and another. A very large number of these departures from the type were mutations in the sense that they had a definite hereditary basis. Inasmuch as

the breeding experiments of de Vries and of Morgan with the mutations which they studied agree with hundreds of experi-

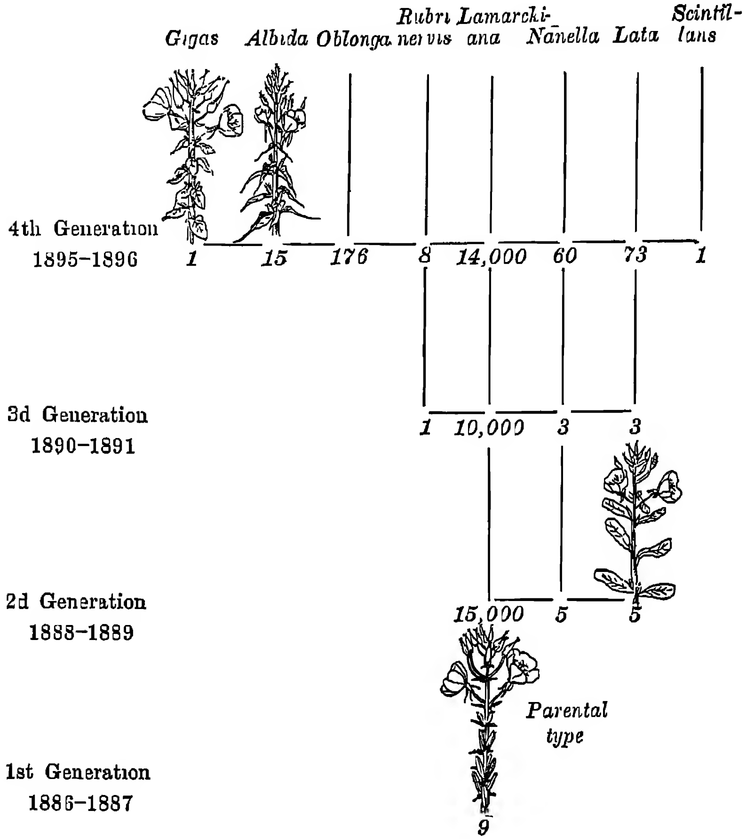


FIG. 48. MUTATIONS IN EVENING PRIMROSES

Among thousands of evening primroses grown from seed each generation yielded from a few to a hundred or more individuals that departed from the parental type in some distinctive way and that reproduced the new characters consistently in the offspring Is some years five or six such mutations appeared. Some mutations appeared repeatedly as offshoots of the old stock kept in cultivation From Gruenberg, Elementary Biology, published by Ginn & Company

ments by other workers with mutations in many species of plants and animals, we are warranted in asserting that

(1) mutations occur in all species more or less frequently, and that

(2) they give rise under favorable conditions to strains presenting new characters.

We cannot here discuss further the meaning of the sporadic appearance of unusual characters in plants and animals without first considering the facts of heredity (see page 311), since the significance of mutations, the existence of which can no longer be doubted, lies not in the extent to which they depart from the ancestral type, but in the fact that the deviation whether large or small is transmitted to subsequent generations. It is the *discontinuity* of the mutation that distinguishes it from the fluctuations, which result apparently from the action of a multitude of factors upon the developing individual and which are not transmitted to offspring.

Can Artifical Breeds Maintain Themselves?

It is impossible to say whether artificial species, or those that emerge through artificial breeding, protection and selection, can maintain themselves in a state of nature. Some certainly cannot. They depend upon special care and protection against extremes of temperature, against insects and other enemies. Many cultivated plants would be quickly exterminated by their natural enemies, and by their competition with "weeds," if left to themselves. On the other hand, cultivated varieties of wheat will resist the rust as none of the "natural" varieties seem to have done in the past. Whether these particular varieties can maintain themselves under wild conditions, however, is important for our purpose only in relation to the question of adaptation. Are such strains fit to live? Here we must again remember that fitness is a matter of reciprocal relationship. It is always relative. The tiger is fit to live in a tropical jungle; the polar bear is fit to live in a different environment. With external conditions constantly changing, the plant or animal that is fit or prosperous today may tomorrow be on the way toward extermination.

If we could breed among animals in captivity to yield a new artificial species which is in every respect like the tiger of the Indian jungle, we should have an animal that could not maintain itself adequately in the wilds of Kansas, let us say. Yet this would be in every respect as real a species as the tiger that does maintain itself in Asia, where our artificial species could also live. Our species artificially established may not be fit to live if given its freedom in the neighborhood of the laboratory, but may nevertheless adjust itself to a natural environment of another type. The requirement that an artificially produced type, in order to be considered a new species, be able to maintain itself under natural conditions may be fair enough; but it is not fair to test such an artificial creation by placing it arbitrarily in any natural environment at random. Nature's own species cannot stand that test.

The conditions of life include the activities of other living things as well as the physical factors of the environment. Whether a given type of plant or animal is to be regarded a genuine species or not is a question of its being able to live at all and to perpetuate itself in distinction from other groups. The fact that sooner or later it may become exterminated in the struggle for life should have no bearing upon this point, for the history of the world is a constant record of such exterminations. On the American continent there lived and eventually died out millions of years before the arrival of Columbus distinct species of horses and camels, of elephants and monkeys. A change in climate may force a species to migrate to remote regions. Certain insects coming out of the ground where they had spent several winters may suddenly find themselves without food supplies and so die out. It is important to these insects that the plants moved away. It does not make them, however, any less "a species" because their food plants have been removed from over their heads and under their feet. A change in the market may lead to the abandonment of potato culture over a large area. Potato beetles coming out of the ground some

fine spring morning find food supplies and breeding places wiped off the face of the earth — that is, their earth. And the tribe perishes without having undergone the slightest change in structure or capacities. The armored dinosaurs were real animals and quite distinct from one another as well as from other reptiles notwithstanding their relatively short sojourn upon the earth of only a few million years. Any factor that upsets the balance of life may cause havoc to one or another species, but while it lived such a species was a true species no matter how it originated.

Misfits

To say that a given plant or animal, regardless of its origin, is a misfit or a failure is to suggest more than is necessary for a consideration of the facts of evolution. It is indeed true that there are born every year countless individuals that are so defective in one way or another that they could not under any circumstances remain long alive. We must nevertheless think of the exterminated misfits of the past exactly as we think of the adapted plants and animals — that is to say, we must consider maladaptation as well as adaptation entirely from a relative point of view. The clearing away of woodland to be replaced with orchards results in the extermination (in a given area) of many plants, of many fungi, of many species of insects. It results also in the increase not only of the cultivated plants under the solicitous care of the orchardist, but also of many uninvited guests. The plant lice that multiply by the million on the fruit tree are, as mechanisms, no more fit than they were a few years ago. They increase vastly in numbers, however, because the conditions in this particular region have become for them more favorable. The actual picture at a given time shows then a radical change in the proportions of the various kinds of insects. Those that have been exterminated are for the time being less fit.

Exactly the same kind of thing has happened with many

species throughout the ages, with the advance of man through the forest and the prairie, with the change in climate, with the rise of continents, with the subsidence of land, with the advance and retreat of glaciers, with the meander of a stream, and so on. Just as a relatively small change in the conditions of life may offer an opportunity for the rapid increase of one species, it may make for the rapid extermination of another. There is a virtual increase then in the fitness of the former, and of the unfitness of the latter, without any essential change in their characters and processes.

Evolution and Progress

The term evolution has been used loosely to suggest an advance or improvement. This, however, is not a necessary implication of the facts of transformation of species, for sometimes successive stages have shown deterioration. It is specialization that progresses in time. The orchids appear later than the lilies. The social insects appear later than the cockroaches. The advance in specialization has indicated in general a more and more precise adaptation to restricted conditions of living, with corresponding advantages of economy. The mammals, for example, can maintain themselves by producing a very small number of offspring, whereas some of the fishes and insects produce hundreds of thousands of eggs a season without increasing in the number of individuals from year to year. The flowering plants that are pollinated by insects maintain themselves by producing a very small quantity of pollen compared to the masses produced by the wind-pollinated trees.

On the other hand, extreme specialization has its disadvantages. The plants and animals of the past that have died out are frequently the most highly specialized among their contemporaries. In our own time, we see many species of orchids dying out because they depend for their reproduction upon the visits of particular insects, which are not present in sufficient numbers to insure the formation of seed

every year. The shelled Cephalopods, of which the pearly nautilus is a living representative, existed in past ages in vast numbers and in many different species. Today the whole tribe is represented by very few species and very few individuals. The saber-tooth tiger was undoubtedly fit to live when he did live. Yet he has gone and has left no descendants. We can only guess what advantages the Irish elk found in the tremendous development of his horns, or what advantage the stegosaur derived from the immense frill which he carried on his back.

It is not necessary, indeed, to assume that these monstrous structures had any adaptive value whatever. Both the elk and the stegosaur died out in time, and there is reason to believe that aside from any difficulties provided by their enemies or competitors, the very development of these specialized structures were themselves handicaps to successful living. We are tempted to generalize from the fate of these extinct inhabitants of the earth, because we find in so many cases the extreme elaboration of ornamentation and unessential structures. We are tempted to moralize on the dangers of excessive attention to the ornate, the over-refinement of detail. But we do not need to extend our speculations for the present: the facts may be allowed to speak for themselves. Modification of type has taken place in the course of the generations. Some of the modifications have found themselves incapable of maintaining a foothold, some of the modifications have left descendants which in turn have carried a tendency to the point of self-destruction.

Parasitism represents a type of adaptation which again carries with its many advantages the obvious danger of over-specialization. The parasite that confines itself to a particular host may continue indefinitely to furnish its share of the earth's inhabitants, but if anything should happen to the host species, the parasite is doomed. When a parasitic species is exterminated because for one reason or another the host species failed to supply it with a suitable medium, we are again disposed to moralize on the wickedness and the ultimate

disadvantage of being a parasite. Generally speaking, the emergence, spread and extinction of species go forward with no relation to our own preconceptions of goodness or beauty.

While in general progressive specialization facilitates life and makes possible the intrusion of living things into the gaps left by other species, it carries with it the danger of extermination when the specialized conditions are modified, as sooner or later they must be. We find accordingly that there has been in the course of evolution not only such progressive specialization with the passing of time, but also a persistence through the ages of rather primitive types that have survived all the changes. The horseshoe crab is often referred to as a living fossil because it is the sole survivor of the time when its nearest relative (the trilobites, see page 30) were living in vast numbers and in a great variety of forms. Species of protozoa have continued from earliest times with very slight changes in type, and indeed some of the present-day forms are quite indistinguishable from their ancestors in the rocks. There are, however, records of highly developed insects that have also persisted through millions of years. Among the best preserved fossils are lumps of amber, the hardened resin of trees of ancient times. In these we find buried entire bodies of insects of these former periods, and in comparison with them certain modern species show no changes through all these years.

Isolation

In the Sandwich Islands, which are of volcanic origin, the sides of the central peaks are furrowed into relatively deep valleys by the mountain streams. In some of these islands it has been observed that each valley maintains a distinct species of snail. Yet all these snails are so much alike that they are easily conceived to have had a common ancestry. There are recognized nearly a thousand distinct varieties of which some two hundred are considered good species. In recent years Professor Crampton has made an intensive study of land snails from Tahiti, and finds all the

facts in harmony with the assumption that individual variants capable of transmitting their distinctive characters had become isolated in these various valleys and eventually supplied the snail populations for them. There is not the kind of difference between one valley and the next that would call for specialized adaptation. The living conditions and the food substances are substantially the same. The effect here is as if a mutation had been segregated to prevent swamping by the parental type. In the practical isolation provided by the land formation hundreds of varieties have been able to establish distinct populations. In a similar way, each of the islands of the group contains species not found in the others, and yet all are obviously derived from a common source.

Professor David Starr Jordan formulated some twenty-five years ago, as a result of extensive regional studies of fish, the following general principle: " Given any species in any region, the nearest related species is not likely to be found in the same region, nor in a remote region, but in a neighboring district, separated from the first by a barrier of some sort, or at least by a belt of country the breadth of which gives the effect of a barrier." Dr. Jordan's generalization was based merely on facts observed in the field and is abundantly supported by observations among many different kinds of animals. At the time these observations were formulated the distinction had not been clearly made between genotypes and phenotypes, or between mutations and fluctuating variations. Darwin had recognized that any new character, however it might arise, would be in danger of rapid elimination through swamping by the overwhelming numbers of the conventional forms unless it were in some way segregated.

Life is Flux

As we look upon the world of living things, we see it in constant flux. Every individual changes as it lives. Growth and maturity mean a developmental change. From moment

to moment, also, the individual responds to what is going on without, and its various parts coördinate and compensate their processes in relation to one another. Every random grouping of living things is constantly changing. Its constituent plants and animals undergo their respective fluctuations of activities from moment to moment. The changing season imposes conditions of growth and decline. The plants and animals devour one another and exchange materials and services. There is the further alteration of the group by natural deaths, by emigration and by immigration. If we consider a group like a species, we again find variability a constant feature. The composition of the living population is constantly changing for the reasons suggested as applying to the living individual and to the random group. In addition, the pressure of population tends always to spread the individuals in all directions. New conditions, new situations have to be met. Since no two individuals are alike, and since no two situations are alike, conditions are met with all degrees of effectiveness or failure. The composition of the species is thus flowing now in the direction of the swift, now in the direction of the tough, now in the direction of the sensitive, and so on.

The evidence does not show that the selection of the ordinary " struggle for existence " steadily changes the make-up of a species in a consistent direction. It does show, however, that in addition to the adjustability of the individual to the short-time changes, there is an adaptability of the species to long-time changes. It shows, moreover, that corresponding to the plasticity of the individual is the variability of the species, and that certain types of variables are preserved in succeeding generations. In other words, although variability is not a proof of evolution, in the historical sense, it is an essential condition of the transformation of species. And it is seen to be ever present in a form that makes evolution or the transformation of species not only possible, but the most probable outcome of the constant change which is life.

Elliott & Fry

CHARLES DARWIN

ENGLAND 1809–1882

Chapter 7

Changing Human Nature

EVERYBODY old enough to vote has been impressed with the doctrine that you cannot change human nature. Although human beings have been described as behaving sometimes like a pig, sometimes like a donkey or a goose, we realize that after all these similes stress only fragmentary and superficial resemblances. Nobody really expects a human being to become a lion or a cucumber vine. It is in the nature of the human being to remain always and everywhere human, as it is in the nature of the cabbage to remain always and everywhere cabbage. At the same time, along with the categorical continuity of the human race there may be an actual change in essential characteristics, a real evolution. It is inconceivable that evolution can go on without variation. It is in actual variations, therefore, that we should look for the first indications of evolution, even though the existence of variations does not of itself demonstrate evolution.

Our first problem in trying to find out whether human nature remains fixed or undergoes change is to formulate as definitely as possible just what constitutes human nature. But this is no simple matter, for we are confronted at the very start with a marvelous variability in the so-called human race. It takes all kinds of people to make the world, as we know it.

Without Prejudice

A chemist called upon to report on the metal in royal jewels and in less sacred materials will use exactly the same

methods of analysis in both cases. That is, whatever value his technique may have must be applied without prejudice as to the emotional associations that the material in hand may carry. The chemist would also apply the same methods to determine the composition of a given bone without prejudice as to whether it was the bone of a fish or of a human being, the bone of a beggar or of a bishop. It is in the same way that the zoölogist applies his principles of classification and analysis to the samples of life which come to his attention. When he comes to classify the mammals he includes among them men and mice as well as elephants and whales. It is impossible to define our notion of *mammal* in a way that will exclude man and yet include all the others. Here is a class of backboned animals in which the skin covering is typically hairy; in which the blood is maintained at a fairly constant temperature; in which the jaws are enclosed by flesh and skin and carry enameled teeth in distinct sockets; in which the fertilized egg hatches into a formed young within the womb of the mother; in which certain skin glands produce a characteristic nutrient fluid used by the young; in which the two pairs of limbs are typically provided with five digits.

If we consider the various orders of mammals we are confronted with the problem of either placing man in an order by himself or of combining him with the apes and monkeys, into the order of primates. Again it is impossible to define *primates* in a way that will exclude man but include all the other mammals that properly belong in this order (see page 75). In other words, we are forced to define man as a kind of vertebrate, a kind of mammal, a kind of primate.

In tracing the ancient history of different classes of animals, the paleontologist is obliged to depend entirely upon skeletal structures, since it is very rarely that anything more is available for his study. Basing his judgments on a comparison of the various bones and of the teeth, he traces through the fossils lines of descent and family trees. On

such evidence it is concluded that the primates originated in all probability, along with the carnivora or flesh eaters (dogs, cats, bears, etc.), from a generalized insect-eating mammal having primitive teeth, a large brain and arboreal habits. The earliest fossils of primates are found in the lower Eocene of Europe and of North America, but the indications are that this whole branch originated in Asia and migrated thence under pressure of increasing cold.

The Cradle of the Race

We do not know where the human race first made its appearance upon the earth. It is possible that the species had more than one distinct origin from subhuman ancestors. The fossil records tell us about relatively late humans in Europe and Africa. Records of the earliest types found are fragmentary and too widely scattered to warrant any conclusions. There are, however, other facts which point to man's origin in central Asia.

It was in this central plateau of Asia that the principal families of mammals seem to have originated. There is evidence of successive migrations from this region, indications of waves of off-shoots from the parental stocks moving toward the edge of the continent, across connecting bridges to Africa, to Europe, and to the Pacific islands. These migrations are indicated both by the distribution of fossil remains and by the evidences of a succession of glacial epochs, in the course of which radical climatic changes took place and the forest areas were shifted.

The distribution of present-day races suggests that the migrations of ancestral human beings have followed a course similar to the migrations of other families of mammals. The more primitive types are farthest removed from the region of supposed origin, at the ends of peninsulas, at the tips of continents and on islands. This distribution is in harmony both with the assumption of successive waves of off-shoots

migrating from a central region, and with the needs of adaptation. It is only in such remote corners that the less developed types could maintain themselves. This we infer from considerations of climatic conditions, of the concomitant food supply, and of competition with more highly developed types of later origin.

There is a widely prevalent notion that man originated in the tropics. This is on the theory that only in a genial climate and in the midst of abundant vegetation and game could primitive man survive. Opposed to this view is the fact that all races (those of the tropics as well as those of the extremely cold regions) seem to be at their best in an atmosphere corresponding to the temperate regions, that is, at a mean temperature of about 60° to 70° Fahrenheit, and in an atmosphere with varying relative humidity. Even the equatorial negroes seem to be more healthy and more energetic under such conditions than they are in their native environment.

The absence of hair is taken by some anthropologists to indicate at least a very long sojourn of our ancestors in a region that encouraged the use of clothing, probably the skins of other animals. It is of course impossible to say whether primitive man resorted to such external covering after the loss of hair had made the additional protection necessary, or whether he lost his own fur after he took to using that of his neighbors. In either case there is implied a progressive adaptation, or the transmission of the effects of use or disuse; and regarding this it is impossible to speak positively. It is interesting to note that tropical mammals that have lost their hair have become characteristically thick-skinned, as illustrated by the elephant, the hippopotamus and the rhinoceros. These thickenings of the hide we assume to represent a protective compensation, although again we are entirely in the dark as to the mechanism by which such change could have come about. At any rate, the fact that man alone of the mammals has acquired a more tender skin along with the loss of hair is taken to indicate that the use

of some covering made possible his survival without the development of a tougher or a thicker skin.

Man's Antiquity

Remains of early man have been found in North America, in South America and in Africa, but these generally leave considerable doubt as to their age and as to the

Pithecanthropus *Heidelberg* *Crô-Magnon*

FIG. 49. THREE STAGES IN HUMAN DEVELOPMENT

Restorations to suggest probable appearance of three primitive types of human beings. Photographs of figures molded by Professor John H McGregor on the basis of fossil fragments discovered from time to time in various parts of the world From Gruenberg, Elementary Biology, published by Ginn & Company

characteristics of the beings who left them. Most of the evidence we have regarding early man comes from various European fossils, many found in association with chipped flints and other indications of human handiwork None of the unmistakably human relics occur in rock formations older than the great ice age, the so-called Pleistocene or Quaternary period. Some specimens recently found in East Anglia, however, suggest the possibility of human beings in the later part of the Tertiary period.

The first find of distinctly human fossils was made in 1856, the remains of the now famous Neanderthal man (Fig.

50). At the time there was a great deal of dispute as to whether the bones represented human remains or not. Dr. Rudolf Virchow, distinguished for having founded modern scientific pathology but nevertheless a tight-minded person, attacked the evidence and insisted that the remains represented a freak, or a degenerate person. He could not admit into the human family a being with such a low forehead, with such prominent eyebrow ridges, such a massive jaw, such a retreating chin (Fig. 49). More and more skulls and other bones of the same type were dug up over a larger and larger part of Europe. Stone implements were discovered in association with these fossils. It became at last impossible to deny the human character of the strange, extinct race. For a long time this type was considered a distinct species, a side branch that had been supplanted by *Homo sapiens* migrating, presumably, from Asia. This is indeed the view of Professor Osborn, although other biologists consider the Neanderthal a direct ancestor of modern man.

In 1891 Dr. Eugene Dubois, a Dutch army surgeon, found in Java a skull-cap, some teeth, and a left thigh bone that belonged to the Tertiary period, judging by the rock formation in which the fragments were lying. The skull-cap has distinctly gibbon-like characteristics, while the thigh bone is just as distinctly human, and the teeth are considered as intermediate between the ape and man. The fragments were assigned to an unknown species of primate and given the name *Pithecanthropus erectus*, the erect ape-man (Fig. 49).

The fossil record of man's direct ancestors represented probably no more than fifty to a hundred thousand years of the earth's history, which is after all a comparatively short period. Yet during this period, the facts show, there appeared several distinct types of man from the ape-man, *Pithecanthropus erectus* found in Java, the Heidelberg man of massive jaw, belonging probably to the first inter-glacial time, to the magnificent *Crô-Magnon* and the more recently discovered Piltdown skull and the Rhodesian man of South

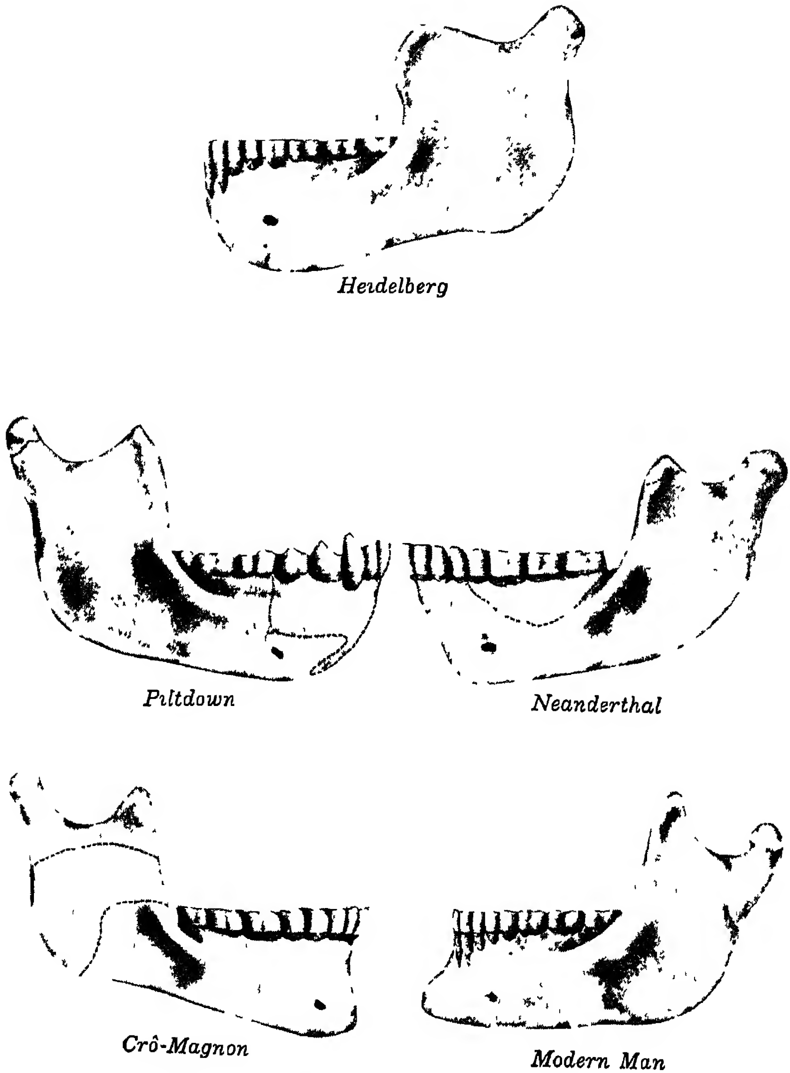


FIG. 50. EVOLUTION OF HUMAN JAW

Fossil remains of human bones show that there have been progressive changes in the jaw from the chinless jaw of the Heidelberg man, resembling that of the gorilla, to the less massive jaw, with more prominent chin, of modern man, and there have been corresponding changes in the teeth.

Africa (Fig. 50). If we go from the oldest of these fossils to the more recent we find that there has been a progressive change in the skull involving an elevation of the forehead and a reduction of the brow ridges. With these has gone an enlarged brain (the fossils show of course only the brain-case or cranium), and especially an enlargement of that portion of the brain which is related to the higher mental processes and to speech (see Fig. 51). The following table gives the average brain capacity of a series of human types between these extremes. It should be noted that in many cases the number of samples from which the average is taken is very small and in a few cases only one.

BRAIN CAPACITY (After Osborn 1927)

Pithecanthropus erectus	940 cc.
Indian Veddahs	1000 cc.
Piltdown of Sussex	1070 cc.
Average Modern Swiss	1200 cc.
Living Broadhead Czecho-Slovakian	1230 cc
Papuans, New Guinea	1236 cc.
Native Australian	1310 cc.
Upper Paleolithic Broadhead	1400 cc.
Average Modern European	1450 cc
Crô-Magnon	1550 cc.

Pre-human Origins

The stock of primates from which Homo probably descended is unlike any of the present-day apes. It has been impossible, however, for paleontologists and anthropologists to agree upon one of the fossil types as the probable common ancestor of man and the anthropoids. The difficulty is due entirely to the absence of adequate fossil records. In recent years there have been found both in Egypt and in India jaws and teeth of several genera that are on the one hand more primitive than the earliest apes, but that show, on the other hand, definite indications of human traits, especially

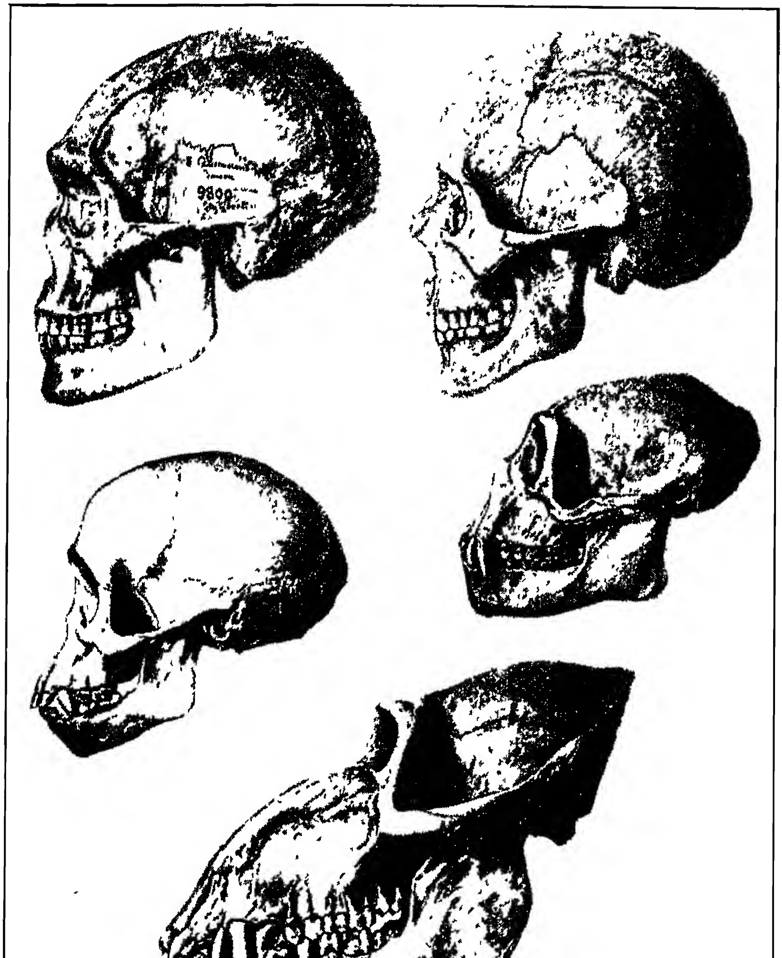


FIG. 51. PRIMATE SKULLS

Australian, European, chimpanzee; gibbon; mandrill After Haeckel Photograph by American Museum of Natural History.

in the teeth. Thus, the *Propliopithecus* of the Egyptian Eocene has a molar tooth pattern that might have led as readily to the anthropoid as to the human type. During the following fifteen million years there was an increasing number of anthropoid forms characterized by the same basic tooth pattern as that found both in anthropoids and in man. The forest ape *Dryopithecus,* which became dominant in Miocene times, was an animal about the size of the modern chimpanzee. It had powerful canine teeth resembling those of modern apes. On the other hand, the molar teeth were remarkably like modern human molars, while the chin was also more like man's than like the modern chimpanzee's or gorilla's. It is on such facts as these that Professor W. K. Gregory rests the theory that *Dryopithecus,* or a close relative of this type, was the common ancestor of modern anthropoids and of man, although President Henry Fairfield Osborn would expect to find a common ancestor in a more primitive type of a much earlier period.

At the present time the divergence between the Old World monkeys and the New World monkeys, between the monkeys and the apes, between the apes and man, are so great that they indicate a very rapid change in type during the sixty to one hundred million years that have elapsed since the most primitive primates made their first appearance. This end result of wide divergence is significantly related by Professor Gregory to the exceptional variability of all human and anthropoid material which has been studied. That is to say, out of a given number of specimens of such material, there is more difference between extreme measurements or proportions than is found in a corresponding lot of material representing other orders of vertebrates, let us say the ungulates or the carnivora. This greater variability would mean more rapid modification of forms, no matter what theory we may adopt as to the actual mechanism by which change of type has been brought about.

Man and Other Primates

Modern man differs from ancient man. He differs also from other primates, both living and extinct. It is interesting to compare the facts about these three groups of living forms — modern man, ancient man and manlike beings, and other primates. Such a comparison brings into relief the characteristics that have in the course of time accumulated and combined to produce the human race — or races — that we know today. These characteristics are the erect posture; the liberation of the hands and arms from the needs of locomotion; the enlarged brain, and especially the forebrain; the liberation of the mouth from the need of holding and rending food; the reduction of hair; increase of sociability and communal living. These characteristics are subject to observation, they represent facts. They do not of themselves, however, tell us that they were *achievements in time*. For all we know, man has "always" been like that — has always, that is, from a moment in the past when all the primates may have appeared, differed from other forms of life. That the modern human form has descended from different forms we can infer only from the records left by ancient man and ancient sub-human beings.

The biologist and the anthropologist go farther. In addition to describing certain characteristics that differentiate man from other primates, they speak of some of these characters as acquired changes, or as deviations from earlier forms. Some of these changes for which there is a record include the diminished brow ridges, the more erect posture, the shorter arms, the better thumb, the reduced muzzle and teeth, the lessened jaw power, the increased chin prominence, the increased cranial capacity. Throughout the evidence is not merely that man has more of this or less of that, but that *there has been an increasing or a diminishing*.

The characteristics of man were probably not all independent achievements. Some of them are closely related to each other in the workings of the body, and some of them

are probably closely related as groups of hereditary characters. For example, both the head and the hand are probably related in their development to the erect posture, as is the development of the foot. Inguinal hernia (which is unknown among the lower mammals) and the distinctive curvature of the spine are also related to the erect posture.

We have had impressed upon us the similarities between man and other primates. It is well to recognize also the underlying differences. The more important of these are shown in the table on page 206, compiled from President Osborn's work.

Monkey Tails and Other Superfluities

Because of the associations and prejudices which most of us take on early in life, we almost inevitably consider the presence of a tail in human beings either frivolously as a joke or solemnly as a humiliation. But there are occasionally human individuals (a very small fraction of the population, to be sure) who have definite tails, though these are seldom very long, and never active. Moreover, during a very early stage in the development of the individual, the series of vertebræ that make up the backbone extend beyond the limbs into an unmistakable tail (Fig. 52). In most cases, these terminal vertebræ are absorbed so that at the time of birth there remains no external indication of this structure.

As we have seen, there are numerous other structures and details which are taken by the biologists to indicate that mankind in some remote past was different from the human race of today (see pages 97 ff). There is, for example, the problem of the mammary gland. Linnæus established the order of mammals to which he gave the name Primates, and he distinguished it from the other mammals by the fact that whereas in the lower orders there are several pairs of mammary glands, in this order there is only one pair. But the glands are present not only in the female, where their function is obvious, but also in the male, in a rudimentary state.

Moreover, there occur from time to time human beings, males as well as females, in whom are present two or three pair of supernumerary mammary glands. These are sometimes spoken of as "reversive" or "atavistic"; but such characterizations assume that we understand something of their causation. These supernumerary mammary glands seem

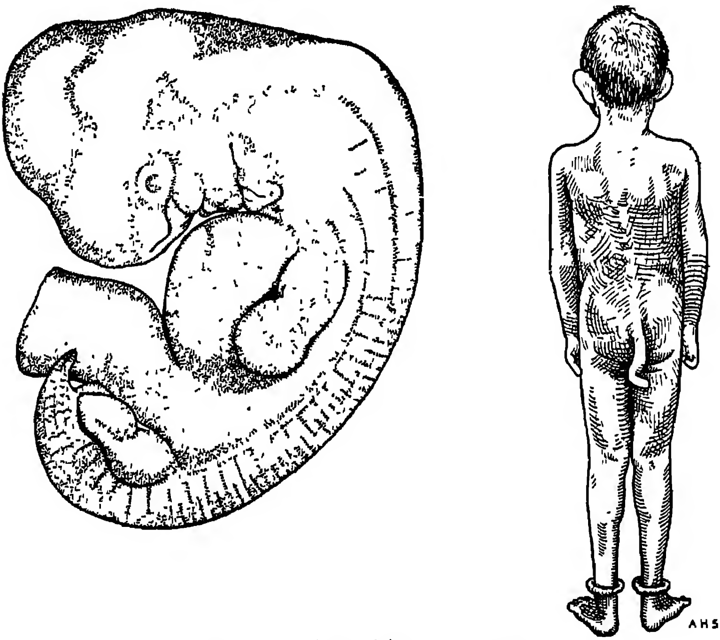


FIG. 52. THE TAIL OF MAN

During the early stages of development every human being has a tail that projects well beyond the beginnings of the legs During development this region is usually overgrown so that at birth there is no sign of the appendage Occasionally, however, a child is born with a distinct tail. The one shown here was a twelve-year-old boy from French Indo China, with a tail nine inches long. From drawing by Dr Adolph H. Schultz embryo after Conklin, Heredity and Environment, published by Princeton University Press.

to have significance for an evolutionary interpretation since several pairs of glands normally occur in the embryo of each individual, and in most cases all except the pair on the breast disappear. These facts, taken together, leave something to explain unless we assume that in the course of time a progressive specialization from many pairs of glands to a few or one, and a progressive differentiation of maleness and femaleness,

CONTRAST BETWEEN MAN'S FAMILY AND APE FAMILY

(After Osborn)

	Pro-Human Characteristics	*Pro-ape Characteristics*
1	Progressive intelligence; rapid development of forebrain	Arrested development and brain-size
2	Ground-living biped; habit adapted to rapid travel and migration over open country	Arboreal to hyper-arboreal quadrumanal; habit adapted to living chiefly in trees
3	Development of the walking and running type of foot and great toe	Quadrupedal habit followed when walking on the ground
4	Shortening arms and lengthening legs	Lengthening arms and diminishing legs
5	Walking and running power of the foot enhanced by enlargement of the great toe	Grasping power of the big toe for climbing, modified when walking
6	Development of the tool-making thumb	Loss of thumb and absence of tool-making power
7	Adaptation and design of implements of many kinds in wood, bone and stone	Adaptation of the foot and hind limbs to the art of tree climbing
8	Design and invention directed by the intelligent forebrain	Design limited to the construction of very primitive tree nests
9	Use of arms and tools in offense and defense, and in the arts of life	Use of the arms chiefly for tree-climbing, and secondarily for the prehension of food and grasping of the foe
10	Use of legs for walking, running and travel to escape from enemies	Use of legs in tree climbing and limb grasping
11	Escape from enemies by vigilance, flight and concealment	Escape from enemies by retreat through branches of trees
12	Tree-climbing by embracing main trunk with the arms and limbs, after the manner of the bear	Tree-climbing always along branches, never by embracing the main limbs and trunk

went hand in hand with other differentiations, because of which we distinguish " higher " forms of life from " lower."

There is the arrangement of the hairs on the arms of man. These hairs, whatever " use " we may ascribe to them, run in a direction for which no explanation has yet been suggested on the theory that these structures, like all the others of the living thing, have meaning in the sense of fitness or adaptation to the interests or welfare of the individual or the species (Fig. 53). On the other hand, the assumption that at some remote past man's mode of life was different from that of the man whom we know offers a reasonable explanation.

Man *Male Chimpanzee*

FIG 53. HAIR TRACTS ON THE ARMS

The curious arrangement of the hairs on the arms of anthropoids — from the wrist and from the shoulder toward the elbow — suggests an adaptive value among tree dwellers A similar arrangement in man is not so easily explained After Romanes.

Embryological Evidences

We have learned to take for granted individual variation among familiar persons. As large numbers of individuals and fetuses are compared, we find that every part of every individual shows such variation at every stage of growth. Now, a comparison of adults with infants and fetuses, in respect to variability of parts, shows that structures which deviate little among adults have varied little in the course of development, and they have varied little from the ancestral conditions. This means

that the most extensive changes take place in those structures that are most variable. Whether we compare different stages in human development or different species in the larger group of primates, the same is found to be true.

Dr. Adolph H. Schultz of the Johns Hopkins University, who has made thousands of such studies on very extensive material, points out that in the evolution of species as well as in the individual development three kinds of changes are possible, theoretically:

(1) The changes may be consistently divergent — that is, as time goes on one individual, or one species, comes to differ more and more from another.

(2) The changes may be strictly parallel to each other, so that species or individuals remain equally distinct from one another at every stage of evolution or of development.

(3) The changes may be convergent, so that with the passing of time the individuals of a species, or the species of a family, become more and more alike.

The actual studies, including thousands of comparative measurements of human and other primate individuals at all stages, show strikingly consistent results. In not a single instance has there been convergence — that is, in no case do the parts compared show a tendency to become more alike, whether among individuals, or between different races of mankind, or between different species of primates. "All human racial differences and all differences between man and apes or monkeys increase during some periods of growth and remain the same during other periods, but they never become less with advancing development."

Human Races

The evidence that the human race has changed with the passing of time is necessarily scattered and fragmentary. The archeological and paleontological evidence can, however, be supplemented by a study of man as found upon the earth today. It we undertake to classify the whole human popu-

lation into races or subspecies, we have essentially the same problem as that of defining numerous species of the same genus. This, as we have seen, involves either the drawing of perfectly arbitrary lines of separation, or the frank assumption that the several types are related in the sense of having common ancestors from which they diverged in the course of their descent.

The classification of races most widely accepted is that of Blumenbach, who at the end of the Eighteenth Century divided man into five groups: the Caucasian, the Mongolian, the Indian, the Ethiopian and the Malay. This classification on the basis of color has the advantage of convenience and fairly ready recognition. A simplified form of this classification which has been used by anthropologists establishes only three major groups: the white, the black, and the yellow-brown, which includes red.

Another attempt to divide mankind into recognizable races is based on characteristics of the hair: the straight-haired, the wavy-haired and the woolly-haired. The physique has also been a very useful means of classifying people, and three basic types have been recognized: the medium physique or Mesomorph, the underdeveloped or Hypomorph, and the overdeveloped or Hypermorph. These distinctions are not primarily of size but take into consideration the proportions of the trunk and the limbs, the head, the nose, the ears, and so on, or the degree to which the features are specialized or well defined. It also cuts across the other classifications, so that the three main types of body build may be found among the various color races.

Racial Overlappings

It is commonly assumed that whichever outstanding trait we may use as a basis for defining a race, several important characteristics are associated with it. People are not merely white or black, not merely straight-haired or curly-haired. At the same time the correlation between the various

characteristics is not very consistent. For example, if we take the three main groups, the white, black and yellow-brown, we shall find that most of the other characters fail to connect themselves in a consistent series with these major divisions. Thus, the whites as a group have the largest brain and the blacks the smallest brain, on the average; and the yellow-browns a brain of intermediate size. In the whites the nose is high and thin whereas among the blacks it is broad and flat; and the yellow-browns are again intermediate. Yet we cannot conclude that the yellow-browns are intermediate between the whites and the blacks with respect to other characters, for this is not the case.

Among the Ethiopians we find the relatively longest legs, and among the Mongolians the shortest legs. With respect to this trait the Caucasians are intermediate. The yellow-browns have straight hair and the blacks woolly hair; again the white race or races will be seen to occupy an intermediate position. Similarly the yellow-browns have the relatively longest ears, the blacks the relatively shortest ears. The yellow-browns have the highest cephalic index (ratio of width of skull to length), and the blacks the lowest. The hair covering of the body is greatest among the whites and least among the yellow-browns. In this the blacks are intermediate.

On the European continent, which has been occupied by white peoples within historic times, we find considerable range as to stature, pigmentation, character of the hair and body proportions. Generally speaking, peoples occupying the seashores and ocean islands are more slender than those occupying central areas of a continent. Thus the inhabitants of Ireland, Scotland, Wales and southern England are taller and have narrower faces, while the natives in the middle of the continent are short and stocky.

Among all races of mankind are to be found variations in body form corresponding roughly to the slight slender type, to the short stocky type, and to an intermediate form. But these types are not found in the same proportions in all races.

Among the yellow-browns all three types are found in considerable proportions. Among the whites there are mostly the medium type and the hypermorphs or slender forms, with very few of the dwarf type. Among the blacks there is a larger proportion of the hypomorphs or infantile type, than among other races, and very few hypermorphs if any, in " pure " stocks.

Moreover, the proportions of these various types seem to be undergoing a change, quite aside from the effects of inter-racial mating. When large numbers of measurements are brought together the curve of distribution is found to be skewed in the direction of the more slender type of build.

Constitutional Types

Recent intensive studies of hospital patients in this country and in Germany show a tendency for certain types of diseases to be associated with certain types of body form. For example, individuals of fleshy build are more likely than slender types to suffer from hardening of the arteries, diabetes, kidney disease and apoplexy; whereas the slender type is in general more subject to tuberculosis, pneumonia and nervous disorders. The study of family histories for the purpose of discovering hereditary traits would indicate that slenderness, as against the fleshy build, corresponds to a recessive factor in heredity, notwithstanding the probabilities that the actual development of the individual is influenced through the action of the endocrine glands. In general, slender parents will be found to have only slender children, whereas fleshy parents may have both slender and fleshy children since either or both of the individuals may come of mixed parental types.[1]

[1] In the language of the student of heredity, a recessive character in the offspring of a mixed mating is concealed by the corresponding dominant (see page 232). That is, all the offspring resemble the dominant parent with respect to the character in question. In subsequent generations of hybrid parentage, the two alternative traits become separated out

It is not assumed that the actual body form of an individual is determined by a single factor. In the matter of human stature alone, at least four factors are involved (see Fig. 54).

In any given population we may find the different body types distributed in some relation to social or economic classes. Thus, the slender type, which is present in a comparatively small proportion of the Japanese population, occurs five times as frequently among the official classes as among the laborers; whereas the short stocky type, which constitutes more than half the population, occurs nine times as frequently among the laborers as among the officials.

Glands and Types

The existence of these varied types has been attributed to environmental conditions. It has been assumed, for example, that the development of the stocky type is due to a diet relatively poor in iodin, since this element has been found essential to the normal activity of the thyroid gland, and this in turn has been found essential to development. There is indeed a very close connection between the distribution of iodin in the soil and waters of a given region, and the prevalence of simple goiter. We have in our own country large areas around the Great Lakes and in the northwest that have been practically depleted of iodin in the course of past ages. In these areas today there appears an excessive proportion of young people, especially girls, with enlarged thyroids. Domestic animals often show striking effects of the privation of iodin, such as hairlessness in pigs and enlarged head in calves and sheep. Furthermore, it has been established that this deficiency and the accompanying disorders can be adequately overcome by supplying the children iodin compounds in small amounts. Parallel to these facts is the

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in such a way that the recessives remain "pure," whereas the dominants, although appearing to be alike, are one-third pure and two-thirds hybrid like their hybrid parents.

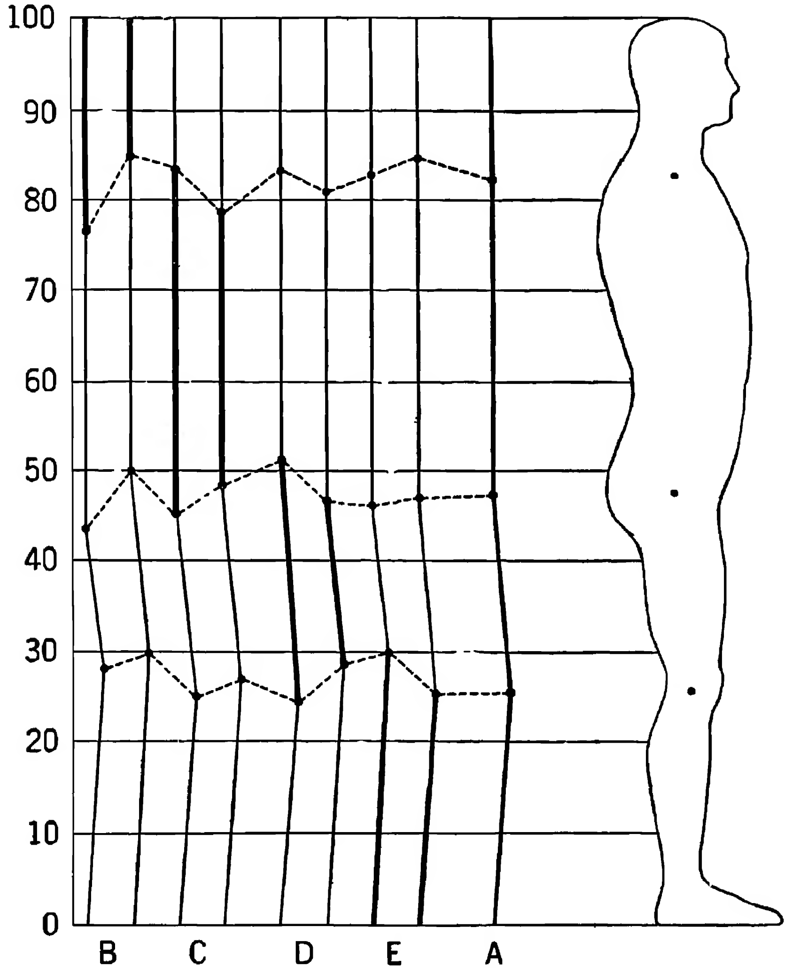


FIG. 54. COMPONENTS OF HUMAN STATURE

The stature of any given person is made up of the sum of four segments, each of which may be determined by factors inherited independently of the others The average proportions of the four segments, based on large numbers of measurements, are shown at A. The extremes found for the head-neck segment are shown at B; the extremes of trunk proportion are shown at C, the extremes of thigh, at D; and the extremes of leg, at E The proportions are given in percentages of total stature. Based on data by Davenport.

well known prevalence of goiter in the mountainous regions of the European continent, and the very frequent association between such goiter and retarded mental development. Cretinism in Switzerland and northern Italy is being controlled by making sure that children have a suitable amount of iodin in their diet.

Defective infants appear from time to time among all races of mankind. Some develop into so-called Mongoloid idiots or dwarfs. These are usually undersized, rather infantile in their bodily proportions, with pudgy rather than well defined features, and with arrested development generally. It is impossible to account for the appearance of such a defective individual in a family that seems otherwise quite normal. There seems, however, to be a definite causal connection between defects in certain structures and the abnormal development of the individual. The Mongoloid idiot type is apparently the result of a faulty development of the thyroid and of the pituitary gland, a structure found at the base of the brain. Considerable success has attended the treatment of such dwarfs with extracts of the pituitary and of the thyroid glands. But we are still in the dark as to what makes the pituitary go wrong, just as we are as to what makes the individual develop "right."

Physiological Variation

There is an apparent correlation between physical development and the endocrine glands on the one hand, and between the physical constitution and physiological characters on the other. In addition, there is the very clear evidence that the so-called races differ among each other in important functional traits. It has long been known, for example, that dark-skinned races are very much more susceptible to such diseases as measles and tuberculosis than are the whites. On the other hand, yellow fever and hook-worm are much more destructive among whites than among blacks.

Temperamental differences among the races are at the extremes just as marked as physical traits. Compare the stolid American Indian with the mercurial African negro, the even-tempered Mongolian with the emotional Irishman. In ancient times these temperamental differences among the races were recognized by travelers, and mankind was sometimes divided into four races corresponding to the four humors of Hippocrates — the sanguine, the choleric, the bilious, and the melancholic. It is obvious that individuals of all temperaments are to be found among the members of any one race, such as the whites for example. There is, however, an increasing body of evidence to establish a definite association between bodily traits and the emotional characteristics. It is very probable that intellectual qualities are also associated with physical traits other than the characteristic size and form of the brain.

In addition to the difficulty of defining races so as to separate distinct types, is the further problem of disposing of numerous human stocks that have become isolated at various times in the past, and that present today confusing loose ends which do not let themselves to be classified at all. There are the hairy Ainus of Japan, the Indian Veddahs, the Eskimos, the Negrillos of Africa, the Laps in Europe, the Siberians in Asia, the Negritos in the Pacific islands, and several minor groups. These isolated groups are in most cases living under conditions that are rather extreme and difficult, so that they are not exposed to conflict with covetous neighbors. On the other hand, while they are able to maintain themselves under difficult conditions, there is neither the stimulation to effort that might lead to improvement of their lot, nor the margin of leisure and energy that might lead to the cultivation of the higher human capacities.

Are Racial Traits Fixed?

The largest body of systematic study of races for over a hundred years had to do with measurements and propor-

tions. It was assumed that the ratio of head width to head length, of limb length to stature, of chest girth to height, and other proportions, are characteristic of races. With the accumulation of more and more data, it became increasingly difficult to maintain the fixity of race characteristics in such terms. At the same time the accumulation of these records made it perfectly clear that the size of the body, the proportions of the limbs, the shape of the head, the form of the face and other features of human beings, *are constantly changing*. These measurements applied to a large body of Americans, descendants of immigrants, showed decided changes of "type," when compared to similar measurements for the parental stocks. In the same way, the descendants of Spaniards in Porto Rico showed decided changes in these proportions and shapes. Similar studies had been made in Germany, showing fairly constant differences between the measurements of city dwellers and those of rural populations. Some students attributed these differences to selection; that is, it was supposed that certain types tend to move to the cities, whereas other types tend to remain in the country. But whether we consider the results due to selection or to the direct influences of environment, it is clear enough that *the constitution of a population does actually change*.

These facts of physical anthropology are in every way parallel to observations made upon domestic animals and upon wild animals in captivity. The head-form and size of skull, as well as size of the body and proportions of limbs, have been found to change in cattle, in horses, in dogs and cats, in lions and rats.

Human Variability

Within a given population every detail of structure in human bodies shows a wide range of variations. We have already seen that stature illustrates the so-called normal distribution (page 159), a characteristic of the chance opera-

tion of a large number of influences (see Fig. 38). From the fairest blond to perfectly black hair, we find a graded series, and another series from reddish tint to very dark brown and black. The unpigmented hair and skin of the Albino represent a mutation and are found more frequently among dark-skinned peoples than among Caucasians. This albinism is parallel to similar phenomena among other mammals, and the conditions of its hereditary transmission have been pretty well worked out. Pigmentation of the eyes, while often associated with pigmentation of the skin and hair, is in some strains an independent variable. We must recognize the existence of several distinct races or subspecies characterized by distinct skin color; but we must see also that there is a considerable range of variation within each race.

The shape of the head, that is, the proportion of the height, length and width, shows a wide range of variability. There is a tendency for each race or for each fairly uniform population to approach a mode in the ratio of length to width, or length to height. But within a given population, these ratios are quite variable.

Most of the people you meet have two arms and two legs. It is very rarely that one meets a person with a third arm or leg. The absence of one arm or leg is not so rare. We do not, however, exclude from our category of human beings a person who manifests an excess or shortage of one of these useful appendages. At the end of most human arms is the hand consisting of a palm and five digits. Occasionally a child is born with a deficiency in these digits. Varying in the opposite direction, there are individuals with supernumerary digits (Fig. 55). Sometimes two fingers are grown together so that they cannot be separated; sometimes the skin extends between two fingers or two toes. These variations we usually look upon as abnormalities, even where they do not interfere with the effective use of the organs. They are abnormal in the sense that they depart from the typical structure. Each finger normally has three distinct joints, except the thumb, which has two. There are individuals

FIG. 55. SUPERNUMERARY FINGERS

Hands of a negro showing supernumerary fingers The right foot is normal, but the left had an additional right toe. The extra fingers are completely functional Photographs and X-ray pictures through courtesy of Dr Dunlap P Penhallow.

who have short stubby fingers consisting of only two joints (Fig. 56).

These examples of deviations from the typical structure, and of fluctuations in the normal form and proportions, are taken for granted. They are sufficiently common in a large population to pass without notice, and they remain well within the limits of our common notion of the human race or species. In respect to some of these qualities we assume

FIG. 56. BRACHYDACTYL HANDS

In some individuals the end segment of the fingers is missing, giving the fingers a short, broad appearance. This condition has been traced through several generations, and seems to behave like a Mendelian dominant. After Farabee; photograph through courtesy of the American Museum of Natural History.

a direct relation to environment. To most people, for example, stature appears to be related to nutrition, or to factors such as disease or strain which may influence growth. Indeed there is a considerable body of evidence to show that large sections of the population living under unfavorable conditions tend to be shorter on the whole than the more favorably situated portions of the population. Moreover, there is considerable recent evidence to show that children in America tend to become taller than their parents were at correspond-

ing ages. The children of Italians living in America are taller than children of corresponding parts of the population in Italy. Japanese children living in America are taller than Japanese children living in Japan, and so on. In England there was a marked decline of the average stature of enlisted men toward the end of the last century. Both in England and in Japan, measurements of enlisted men have in recent years shown a tendency toward an increased stature. In Japan, a study has just been completed of men enlisted in 1892–1926 inclusive. During these 35 years there has been an average increase of height amounting to 1⅓ inches.

Physical and Physiological Differences

Differences in physical traits tend to overlap differences in physiological traits. It is sometimes impossible to distinguish the two. For example, we think of pigmentation as a physical trait since it is apparent to the senses and can be measured with a considerable degree of accuracy. The formation of pigment, however, is the result of definite chemical interactions and may quite properly be considered a physiological character. Differences in voice, in susceptibility to disease, in the rate of maturing, in the production of milk, in the chemical character of the waste products, in blood pressure, in capacity to digest various foods, are examples of physiological traits with regard to which individuals of a given population are found to fluctuate. Recent studies of the so-called blood types [2] show, on the one hand, that each race has a distinct proportion of individuals of the various blood types, and on the other hand, that the blood types are inherited, as are other physical traits.

[2] With improvements in the technique of blood transfusion has arisen the difficulty that the blood of one person may not be compatible with the blood of another. Extensive study of human blood primarily for the medical purpose of determining the suitability of available blood for transfusion in concrete situations has revealed the existence of "types" with distinct modes of reaction.

Differences in intellectual and emotional characteristics are of sufficient concern and practical importance to have received attention for a long time. Our democratic tradition has made us overlook these variations, or it has made us assume that they are either of no great consequence or merely incidental to differences in living conditions. The accumulation of data points to the more fundamental fact that among the many traits with respect to which individuals differ some are of constitutional or hereditary source. It is true today as it was in the past that sows' ears cannot be converted into silk purses. The differences, whether important or trivial, indicate a complex population varying constantly in many directions, and more plastic than most species of living things.

Environmental Factors

As to the causes of these variations we know very little. Some indeed can be traced to definite environmental or developmental agencies. Today there is no excuse, for example, for a child to be rickety even if rickets has in the past "run in the family." We know definitely that a defective calcium metabolism resulting in deficient bones can be corrected by suitable diet or by appropriate irradiation with ultra-violet rays. Many people assume that pigmentation is related to outer conditions. We are all familiar with the effects of sunlight upon the color of the skin. For large parts of the population in all parts of the world there has become embodied in the folklore the assumption that dark peoples are dark because they live in tropical regions and that the pale faces are light because they are sheltered from the sun. To this day most people who have given the matter any thought are continuously puzzled by the question whether dark races are dark because their ancestors had been exposed to excessive sunlight or whether they live in the tropics because they are pigmented and can tolerate the excessive sunlight.

As to the actual process which has resulted in distinct races, we know nothing. It is true that Cunningham was able to reverse the pigmentation of flatfish by arranging mirrors so that the animals were illuminated from the under surface with the result that the adults were white on top and speckled underneath (see page 170). So far as concerns the human race, however, the probabilities are that the various pigment-races represented distinct mutational divergences from more primitive stocks. Hereditary traits such as characterize both the recognized races and numerous strains or families within each population are not the immediate result of the action of the environment. New types have undoubtedly arisen as a result of crossing and segregating groups carrying special combinations of heritable traits. Climatic and social forces probably play an important rôle in this process. The human race as a whole shows its radical deviation from ancestral types in the relatively sudden appearance of a large brain and in the liberation of the hand from the task of locomotion. Such a radical departure was probably a mutation, and in the ensuing lines of descent numerous other mutations have added traits that in their totality give us the human race of today — a very heterogeneous population and yet all human.

The Race in Transition

The question whether human nature has changed or is changing cannot be answered categorically. If change is going on today it is so slow that we cannot observe it directly. If it has gone on in the past our knowledge of it must suffer from the limitations of all historical knowledge. It is worth while to note, however, that not only do the interests and the behavior of peoples vary from place to place, but they have varied through the ages. Fashions have changed in our major values, in estimates of success, in leisure pursuits. Head-hunting is important for some people, while privateering and gambling engage others. The peaceful arts fluctuate

not merely because traditions change or because phonographs are invented, but also because — to an unknown degree — the proportions of various constitutional types are constantly changing in any population. Both such historical information as we have and the statistical study of accessible populations tell us that *change is a constant aspect of human nature.*

It is impossible of course to predict the direction in which these changes are to continue. Three conceivable possibilities remain for the future:

(1) The races and types of the present may remain always the same and their proportions remain the same; that is, with all its variability, the human race may continue the same as it is today through the ages. This is conceivable; but from what we know of the nature of living things, and from what we know of what has happened in the past, extremely improbable.

(2) It is conceivable that the variations may continue to increase while the modal or typical values remain the same. This would leave the "average" or standard qualities unchanged. This too is extremely improbable in view of what we know about the fluctuations or variations in living things.

(3) It is conceivable that whether new variations appear or not the proportions of the different types will undergo more or less consistent changes in one or another direction. This would be a modification of human nature in some determinate direction — in other words, evolution. From what we have seen happening to other living things, all the facts point to this kind of change in human nature, as having gone on in the past, as going on now and as continuing into the future.

Whence and Whither

Many people seem to be more interested in the past and the future than they are in the present. Some unkind individuals say that this is because we are trying to get away from ourselves, from our responsibilities and difficulties.

Perhaps, however, this concern with the whence and the whither is only an illusion, and is prominent only because man seeks in the remote some clue to the immediate. If we only knew whence we came, or what the future has in store for us, we might perhaps shape our day-by-day conduct more effectively, or more satisfactorily.

When we think of the history of the race, the past is shrouded in obscurity. We have at best highly probable conjectures based on the convergence of many kinds of evidence — paleontological and geological, anatomical and embryological, physiological and pathological, anthropological and psychological. No single fact can tell us unmistakably that man is now a different animal from his ancestors of hundreds of thousands or a million years ago. All the facts taken together, however, leave no room for doubt — unless and until a more satisfactory interpretation is offered. Similarly, we have no single fact that tells us unmistakably that the human race as a whole is undergoing change. And again, all the facts taken together point to changes going on in every race, more with some, less with others.

It is thus quite as impossible to predict the future as it is to draw a simple picture of the past. The probabilities are against any radical change in type, any radical improvement in the living mechanism, any radical change in stature. We may be losing our hair, we may be changing to a nearsighted race, our descendants may have flabbier muscles than we have. There is some indication that the "wisdom" teeth are disappearing; fortunately, however, there is no direct connection between the last molars and wisdom. There are indications that certain portions of the brain that have to do with the getting of "knowledge" are being used more extensively, even if they do not increase in size. Unfortunately, however, it has been observed that knowledge may grow while wisdom lingers.

In thus using the terms fortunately and unfortunately we reveal a trait that appears to be confined to human beings. Man is the only organism that gives evidence of having a

consciousness of *values*. He has discovered that life is more than meat, and he has increasingly busied himself with that something which sets him off from all other organisms. This is an important fact. We may recognize it and contemplate it without prejudice as to how man came by this peculiarity. Among other effects, this consciousness of values has led to man's preoccupation with the possibility of influencing the future of the race, not merely in the sense in which social progress may be influenced, but in the sense of improving the race as a living species.

Eugenics and Euthenics

Controversies regarding nature and nurture date back to very ancient times. Everybody seems always to have known that there are inborn qualities in people — at least in some of them — that will somehow manifest themselves under a great variety of circumstances. Everybody seems always to have known also that circumstances do matter — at least for ordinary folks. There have been royal personages of obscure, not to say lowly, parentage. Scions of royalty have not always become kingly personalities. When prince and pauper are transposed in the cradle there is no telling what will happen. It is all very confusing. The controversies so far prove only that we cannot agree.

At the present time a great deal of our surplus energy and wealth and goodwill are directed to improve the conditions of living, to educating, to spreading culture. The great uplift takes for granted the value of improving conditions. A better world will enable children to grow up into better men and women. On the other hand, much effort is directed toward educating us to the folly of relying upon the environment to make a better race. We are told that genius will out. It is not the slums that bring about poor living, it is low down people who create slums. The thing to do is to prevent the breeding of poor people: thus we will eliminate poverty.

The controversy between the euthenists (who stress the importance of decent living conditions) and the eugenists (who stress the importance of being well born) proves that we are not clear as to the factors of the problem. Both are undoubtedly right; and both undoubtedly overlook something of equal importance. As we shall see presently, the issue between nurture and nature is a false one because it assumes that one of these factors is operative without the other, that there are in fact two separable sets of factors for which the two terms stand. There is apparent agreement, however, that the quality of human life may be substantially improved. Whatever we may think of the process by which human nature comes to be changed, there is a widespread feeling that change in essential qualities has gone on in the past, that it is going on now — and that we may hope to learn how to influence the change in the future. That is to say, in one sense or another we are all "evolutionists."

Chapter 8

Experimental Transformation of Species

THE historian is able to tell us with an adequate degree of accuracy something of the succession of rulers of some ancient nation. Perhaps a full series of coins or of postage stamps will tell us such a consistent and complete story. Quite analogous is the significance of a series of fossil plants or animals. The chalk cliffs of England tell us among other things that with the passing of time there appeared a succession of sea urchins having distinct forms. There can be no question about the facts: A preceded B, B preceded C, and so on through the ages. In addition to the difficulties inherent in the historical studies, organic evolution presents the problem of genetic relationships. It is not enough to know that Augustus followed Julius or that Edward followed Victoria. We want to know what relationship there was between one ruler and the next, or between one dynasty and the next.

In historical studies, such information is generally part and parcel of the record that reveals the succession. In the study of the history of plant and animal forms this is not the case. The succession is at best a presumption of descent and is indeed accepted as such where the resemblances, or rather the differences, do not raise any doubts. But the whole crux of the question lies in the very modifications that do raise such doubts. It is one thing to say that ferns *followed* mosses and liverworts, but a very different thing to say that ferns *descended from* mosses and liverworts. It is easy enough to show that deers with large and branched horns succeeded deers with similar and smaller horns, and that these succeeded deers with no horns at all (Fig. 57). It is

quite a different problem to find out whether the successors were also descendants, notwithstanding the marked differences between one type and the next.

It must be recognized that from the nature of the case it is quite impossible to find direct evidence. Even if all the forms successively inhabiting an area were of exactly the same type, the descent of the later ones from the earlier ones would be highly probable but only a matter of inference. We could have a given house occupied for a hundred years

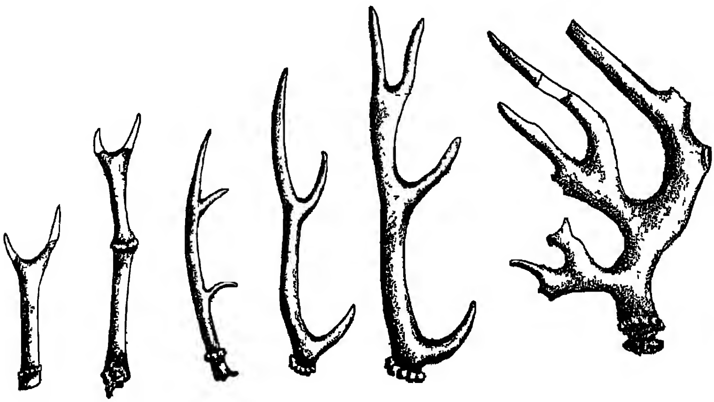


FIG. 57 THE EVOLUTION OF HORNS IN DEER

Fossils of the earliest representatives of the deer family show simple horns. In later and later fossils, the horns branch more and more This fact of the progressively more complex horns corresponding to the later forms is parallel to the increasing complexity of the horns with advancing age of the individual deer today. After Romanes

by Robinsons, but by a succession of different families claiming and recognizing no relationship to one another. On the other hand, the residents in a house might offer the post office a succession of distinct family names and yet be always direct descendants of the original occupants. To find whether succeeding forms are modified descendants it is not sufficient to arrange more or less continuous series. There can conceivably be intergrading or overlapping of unrelated forms. It is possible, in fact, to find well graded series of characters that are known to be of independent origin.

Excellent illustrations are furnished by Professor Thomas H. Morgan from his work with the fruit flies. Among the hundreds of mutations that have arisen in the cultures are individuals with various modifications of the wings, of the eyes, of the legs, and of the abdomen. A series of flies can be arranged whose eyes vary by slight gradations from white, through pink, to brown. Such a graded series suggests the "evolution" from one extreme to the other. As a matter of fact, however, these eye types appeared at various times without any connection between the position in the series and the position in the time sequence. Moreover, these various types did not arise from one another in any definite order but all came from the parental or wild type, mutations having thus appeared independently both in the direction of less pigment and in the direction of more pigment.

Intergrades of Independent Derivation

A series of flies may be arranged in the order of wing size, from very long at one extreme to the merest stumps of wings at the other. Such a series would again suggest the gradual evolution from one extreme to the other. Here too the distinct types appeared at various times without any relation between the position of a type in the size series and its position in the time sequence. The wild type of fruit fly was in every case the parental form from which each of these modifications of the wings arose. There are other departures from the orthodox wing type, such as different degrees of bending or curling. In this series also each of the distinct types has arisen independently without definite time relationship to the origin of the others. (See also Fig. 99.)

The continuity of a series is thus not an indication of the order in which the various characters appeared. There is nevertheless in these experimental studies, and in those of other workers, clear evidence as to the plasticity of the living stock, its capacity to produce new variants in many

different directions. There is clear evidence also that such departures from the parental type may perpetuate themselves genetically.

It is the study of the fundamental facts of heredity since the beginning of the Twentieth Century that has yielded the most convincing evidence of the occurrence of evolution. At the same time it has furnished the most promising basis for understanding how the changes come about. It is these studies that answer for us the question, How can a thing be the same and yet not the same?

The Problems of Heredity

The problem of heredity is present in essence to every mature person who has kept his eyes open and who, without coming to any satisfactory conclusion, has asked the fundamental questions: Why are children more like their parents than they are like other people? Why are not the children of the same parents more alike than they are? The fact of continuity of kind is quite as familiar as the fact of variation — and so far as common knowledge is concerned, quite as great a mystery. It is only our familiarity with the end result, namely that each bears according to its kind, that has made us stop inquiring as to how the result is brought about. Only confusion can come from stressing either heredity or variation at the expense of the other. Both are essentially different aspects of the same fact.

Every mature person has also considered more or less persistently the questions regarding the source of variation: Does A differ from B because of different ancestry, or do the two differ because of different environments or upbringing? Again we recognize the fact of heredity and the fact of environment. Many people would like to have categorical answers to the question, Which of these two facts is more important or more potent? Nothing is gained, however, by stressing either at the expense of the other. Living things being what they are, heredity and environment are equally inescapable conditions of life. Neither concept has

any meaning apart from the other, although in practice as well as in theory we can make distinctions that lead to better control of processes.

Mendel

It was a contemporary of Darwin who, apparently without knowing it, converted all the speculative thinking about evolution into a scientific problem that permitted an attack by experimental methods. Gregor Johann Mendel, an Augustinian monk in an obscure abbey in Brunn, set himself the task of finding out exactly how the numerous characteristics existing among the varieties of the common or garden peas were transmitted from parent to offspring. In a short paper published in 1866, summarizing nine or ten years of study, he said that he considered the experimental approach the only correct one to use if we are "*to reach the solution of a question the importance of which cannot be overestimated in connection with the history of the evolution of organic forms.*" His own results and the subsequent elaboration of his method by other workers have amply justified not only his confidence in experimental research, but in his selection of the problem of heredity as crucial in its bearing upon evolution.

The revolutionary element in Mendel's procedure consisted in restricting his question to a unit small enough to handle. The usual procedure has been for us to think of variations or traits in a given species of plants or animals in their totality. For example, we think of the difference between a spaniel and a hound in terms of spanielness or houndness. We think of two varieties of apples or grapes also in terms of the entire plant or fruit. Mendel analyzed the varieties of peas into the single traits that he could distinguish. For example, some plants are tall and some are short. Some have hairy stems, some have smooth stems. Some varieties have white flowers, some have colored flowers. Some seeds are green, some are yellow. Some seeds are smooth,

some are wrinkled, and so on. A tall plant may have white flowers or purple flowers. Wrinkled seeds may be yellow or they may be green. Mendel noted in all seven pairs of contrasting characteristics which were apparently constant in the different stocks:

1. Ripe seeds smooth or wrinkled;
2. The color of the seed cotyledons yellow or green;
3. Stem tall (6-7 feet) or dwarf (1-2 feet),
4. The pods stiff and inflated or soft and constricted between the seeds,
5. The unripe pods yellow or green;
6. Position of the flowers axial or terminal;
7. Seed coats white or gray to brown.

Dominant and Recessive

Mendel's experiments consisted of crossing plants that differed from each other with respect to a given character, disregarding entirely the other characters, although recog-

RESULTS OF CROSSING GARDEN PEAS WITH CONTRASTING PAIRS OF CHARACTERS

	PARENTAL FORMS (P_1)				HYBRID (F_1)
1 Seed form	smooth	×	wrinkled	—	smooth
2 Cotyledon color	yellow	×	green	—	yellow
3 Stature	tall	×	dwarf	—	tall
4 Pod type	hard	×	soft	—	hard
5 Pod color	yellow	×	green	—	green
6 Flower position	axial	×	terminal	—	axial
7 Seed coat	colored	×	white	—	colored

nizing of course that a plant is made up of dozens of traits. In the course of these experiments Mendel discovered that when a cross is made between two individuals of pure strains that differ from each other with respect to a given character, *all the offspring have the character of one of the parents.* When he crossed a tall and a dwarf, the offspring were all

MENDEL'S RESULTS FROM MATING HYBRIDS TOGETHER

Numbers and (percentages) in segregations, F_2 generation

	Dominant		*Recessive*		*Total*
1 Seed form	5,474	(74.74)	1,850	(25.26)	7,324
2 Cotyledon color	6,022	(75.06)	2,001	(24.94)	8,023
3 Stature	787	(73.96)	277	(26.04)	1,064
4 Pod type	882	(74.68)	299	(25.32)	1,181
5 Pod color	428	(73.79)	152	(26.21)	580
6 Flower position	651	(75.87)	207	(24.13)	858
7 Seed coat	705	(75.90)	224	(24.10)	929
Totals	14,949	(74.90)	5,010	(25.10)	19,959

tall. On crossing a green-seeded plant with a yellow-seeded one, the offspring all bore yellow seeds. On crossing a variety that bore wrinkled seeds with one that bore smooth seeds, the offspring all bore smooth seeds. Mendel found

DOMINANT AND RECESSIVE CHARACTERS IN PLANTS

Name of Plant	*Dominant Character*	*Recessive Character*
Wheat	Late ripening	Early ripening
Wheat	Susceptibility to rust	Immunity to rust
Barley Wheat	Beardless	Bearded
Maize	Round, starchy kernel	Wrinkled, sugary kernel
Maize	Yellow grain	White grain
Maize	Purple grain	Yellow grain
Garden pea	Yellow seed	Green seed
Garden pea	Tallness	Dwarf
Garden pea	Smooth seed	Wrinkled seed
Tomato	Two-celled fruit	Many-celled fruit
Cotton	Colored lint	White lint
Stock Sweet pea Jimson weed	Colored flower	White flower
Sunflower	Branched stem	Unbranched stem
Nettle	Saw-edge leaves	Smooth-margin leaves
Chinese primrose	Palmate leaf	Pinnate leaf

this fact to hold for all the pairs of characters which he studied, and he found it to hold without regard to which of the two parents bore the one character or the other (see tables, pages 232 and 233).

DOMINANT AND RECESSIVE CHARACTERS IN ANIMALS

Name of Animal	*Dominant Character*	*Recessive Character*
Cattle	Hornlessness	Horns
Horse	Trotting	Pacing
Silkworm	Yellow cocoon	White cocoon
Rabbits Guinea pig	Short fur	Angora fur
Cat (in female)	Black fur	Orange fur
Cat (in male)	Orange fur	Black fur
Mice	Normal movements	Waltzing habit
Mice Rabbits Guinea pig	Pigmented coat	White coat
Leghorn poultry	White plumage	Pigmented plumage
Salamander	Dark color	Light color
Canary	Crested head	Plain head
Poultry	Rose comb	Single comb
Poultry	Short rump	Long tail
Poultry	White plumage	Black, buff plumage
Poultry	Extra toes	Normal toes
Poultry	Feathered shanks	Bare shanks
Poultry	Crested head	Uncrusted head
Poultry	Brown eggs	White eggs
Poultry	Broodiness	Non-broodiness
Land snail	Plain shell	Banded shell
Pomace flies	Red eyes	White eyes

Subsequently, systematic experiments along these lines were made with other species of plants and animals. For hundreds of such characters, this general fact holds: of a pair of contrasting characters, one will be found in all the offspring to the apparent exclusion of the other. It is of course impossible to know beforehand which of a given pair

will appear in this manner in the hybrid generation or be *dominant*, to use Mendel's term, and which will disappear or be *recessive*.

DOMINANT AND RECESSIVE CHARACTERS IN MAN

Dominant	*Recessive*
Curly hair	Straight hair
Dark hair	Light hair, red
Beaded hair	Even hair
Hairlessness, associated with lack of teeth	Normal condition
White forelock	Normal, even coloring
Brown eyes	Blue eyes
Normal sight	Nightblindness
Hereditary cataract	Normal eye
Normal hearing	Deaf-mutism
Normal ear	Otosclerosis
Normal pigmentation	Albinism
Hapsburg lip	Normal lip
Normal muscular tone	Low muscular tone
Nervous temperament	Phlegmatic temperament
Supernumerary digits	Normal digits
Fused or webbed fingers or toes	Normal, separate digits
Broad fingers (lacking one joint)	Normal number of joints
Fused joints of digits	Normal joints
Double-jointedness	Normal condition
Limb dwarfing	Normal proportions
Normal growth	General dwarfing
Immunity to poison ivy	Susceptibility to poison ivy

The use of the word dominant in this connection must not be confused with any other implications of the term. There is no suggestion of greater potency, or greater importance. Among mammals, for example, pigmentation in the hair is dominant over albinism; among certain strains of poultry, however, whiteness is dominant over pigmentation. Among rabbits short fur is dominant over long fur; among cattle the absence of horns is dominant over the presence of horns.

Incomplete Dominance

This first important fact, while found to hold for hundreds of characters in plants and animals, is not the universal rule. There are many traits that cannot be in this way

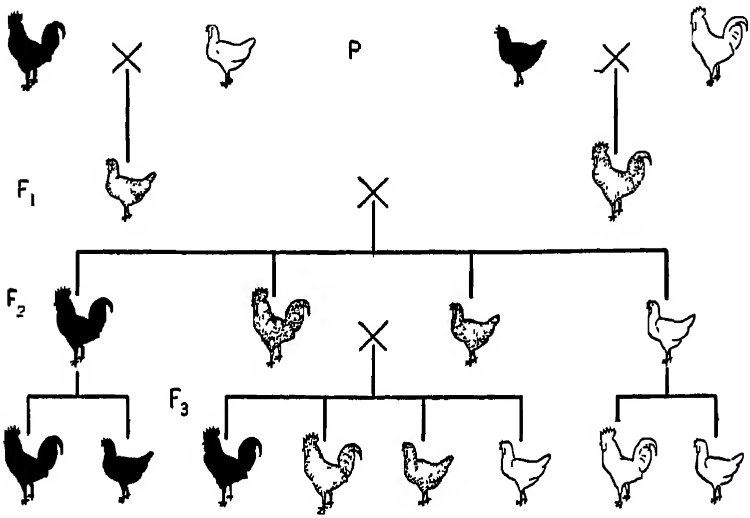


FIG. 58 HEREDITY OF PIGMENTATION IN THE BLUE ANDALUSIAN FOWL

When a black hen is mated with a white cock, or vice versa (P), the offspring (F_1) is always "blue"—really a mixture of black and white speckles in the feathers When two blues are mated (F_1 and F_2) the offspring appears in three types, one half are blues, like the (hybrid) parents, one quarter are blacks, like the black grandparent (P), and one quarter are white, like the white grandparent (P) When blacks are mated with blacks they breed true, whether their parents were hybrids or of pure black stock The whites will also breed true, whether of hybrid or of pure stock. The blues, however, always break up in the way described, whether they are of hybrid parentage or themselves the result of crossing whites and blacks.

separated from their alternatives. In a variety of fowl known as the Andalusian blues, there appear regularly three types—a white, a black, and a "blue" (really speckled white and black). When the whites are bred among themselves the offspring are all white. When the blacks are bred among themselves the offspring are all black. But when the blues are bred together the offspring appears in the three

types in certain definite proportions: one-half are blue, one-fourth are black, and one-fourth are white (Fig. 58). When the whites and blacks are crossed, the offspring are 100 per cent blues. That is to say, the offspring all contain pigment in their feathers, resembling the black parent; but

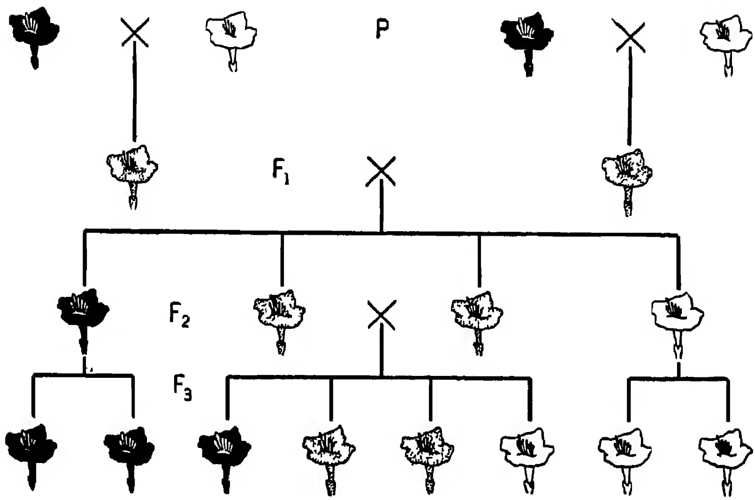


FIG. 59. COLOR INHERITANCE IN THE FOUR O'CLOCK, MIRABILIS JALAPA

When a red-flowered plant is crossed with a white-flowered plant (P), the seeds yield plants bearing pink flowers (F_1) When pink-flowered plants are mated (F_1), the offspring is of three distinct kinds (F_2)· one half bear pink flowers, like their parents, one quarter bear red flowers like their red-flowered grandparents (P), and one quarter bear white flowers, like their white-flowered grandparents. The white-flowered and the red-flowered both breed true

they also differ from the black parent in showing to a degree the whiteness of the white parent.

Among the species of four-o'clock, *Mirabilis jalapa*, some plants have white flowers and some have red flowers. When a red and white are crossed, the hybrid generation bears pink flowers (Fig. 59). In other pairs of contrasting characters studied in the last twenty-five years among many plants and animals, such incomplete dominance has been found repeatedly.

The Law of Segregation

Mendel carried his experiments farther, since new questions grew out of his discovery of dominance. What becomes of the trait that seems to be lost in the hybrid generation? How do hybrids transmit their characteristics? To answer these questions, Mendel crossed some of the hybrid

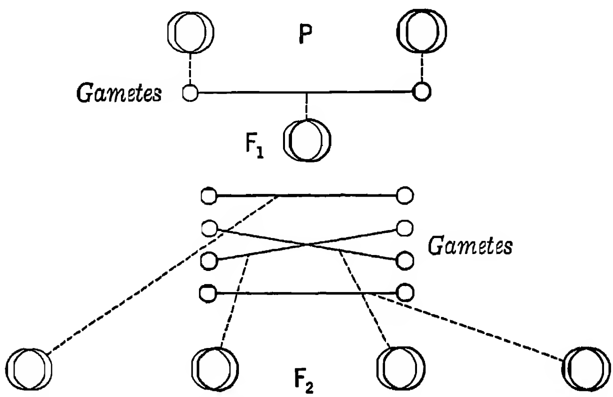


FIG. 60. SEGREGATION OF ALTERNATIVE TRAITS

When two individuals showing a contrasting pair of characters (P, or parent generation) are crossed the offspring (F_1 or first filial generation) will show the character of one of the parents, the alternative remaining latent or concealed The alternative characters are represented by the light ring and the dark ring respectively The "pure bred" individual can produce only one kind of germ cell or gamete, that is, the kind corresponding to the particular character in question — in this case shown by the small circles, light or dark The hybrid individual (F_1) can produce two kinds of gametes, correspondng to the two alternative characters, in equal numbers. When a hybrid male is mated with a hybrid female (F_1), the two kinds of sperms can fertilize the two kinds of eggs in four different combinations, resulting in *three* types of individuals in the next generation (F_2), namely, one combining dominant gametes only, one combining recessive gametes only, and one (twice as numerous as either of the others) combining a recessive with a dominant gamete Since the presence of a dominant conceals the recessive character, F_2 would appear to consist of three dominants to one recessive This diagram applies equally to cases of incomplete dominance, such as the Andalusian Blues and Four o'clock, as to complete dominance, such as Mendel described in the garden pea.

plants with each of the parental types and others he allowed to become self-fertilized. Thus, a tall hybrid was crossed with a pure strain tall; and a tall hybrid was crossed with a dwarf of the parental type. Similarly, plants grown from the yellow seeds of hybrid origin were self-fertilized and

others were crossed with the pure yellow-seeded parental type, and with the pure green-seeded parental type. The results of these experiments with hybrids showed that the dominance of a trait in no sense destroyed its alternative, but merely concealed it (Fig. 60). A hybrid plant bearing yellow seeds is inherently different from a pure strain plant bearing yellow seeds. This difference does not show outwardly but reveals itself in the following generation. *we discover what is inherent by breeding.* It is as true under experimental condition as it is in the world outside, "by their fruits shall you know them." Self-fertilized hybrids produced offspring in which both of the alternative characteristics were present — and *always in a definite proportion:* The offspring of hybrid parents showed three-fourths having the dominant character, and one-fourth showing the alternative or recessive character (Fig. 60 and table on page 233).

On crossing a hybrid yellow-seeded individual with a pure green-seeded individual the offspring show both traits in equal proportions. Here again the hybrid, although resembling the dominant parent, shows that there is something in the constitution that can reappear in subsequent generations, and this can be referred back to the ancestor that manifested the recessive trait. On crossing yellow-seeded hybrids with yellow-seeded plants of the pure parental stock, the yield is 100 per cent of the yellow-seeded or dominant type (see Fig. 61). These experiments show that the two alternative traits found among the ancestors become separated when hybrids are mated. This general fact of segregation of inherited traits has been found to apply to hundreds of characters in animals as well as in plants. No matter how closely the hybrid individual resembles one of the parents, a mating of hybrids will result in the reappearance of the recessive trait in a certain proportion of cases.

We should note here that this principle of segregation applies even where dominance is incomplete. In the Andalusian blues, for example, when two blues are mated the offspring shows three types (white, black and blue) in defi-

nite proportions. That is to say, the white trait and the black trait which the blues have derived from their mixed ancestry are segregated in the offspring in one-half of the generation, while the other half maintains the hybrid appearance of the immediate parents. Similarly the seed of the pink-flowered four-o'clock will produce three types of plants bearing respectively white flowers, red flowers, and pink flowers. And again the proportions are the same — 25

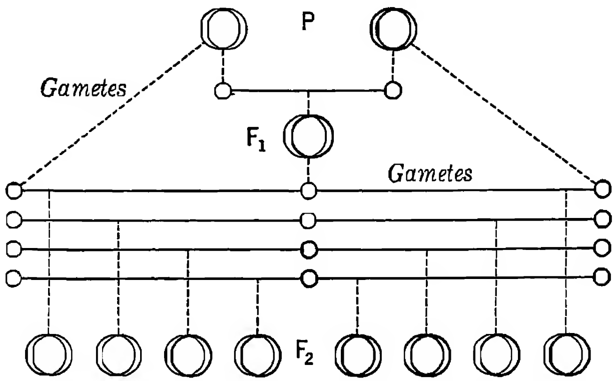


FIG. 61. MENDEL'S EXPERIMENTS IN BACK-CROSSING

What happens if a hybrid (F_1) showing the dominant character of one parent is mated with the "pure" stocks of the two parental types (P)? The dominant parent (represented say by the dark circles) produces only gametes that have the determiner for the dominant character The pure recessive parent also produces but one kind of gamete, that bearing the determiner for the recessive character. The hybrid (F_1), however, although resembling the dominant parent, produces two kinds of gametes If F_1 is mated with the dominant parent line, two kinds of individuals are produced, in equal numbers pure dominants, and hybrid dominants, as shown in the right half of the row F_2. If F_1 is mated with the recessive parent line, two kinds of individuals are again produced, and again in equal numbers: there are pure recessives and hybrids that appear dominant, as shown in the left half of the F_2 row. It does not matter which parent brings in the dominant and which the recessive, nor does it matter which part of our diagram we use to represent the dominant and which the recessive The results of Mendel's experiments lend themselves to broad mathematical treatment, which is presumptive, though not conclusive, evidence of the soundness of his generalization.

per cent white, 25 per cent red, and 50 per cent pink or hybrid type.

The incompleteness of dominance may result in the appearance among the hybrids of a graded series between the extreme types presented by the parents. Among the fruit

Johann Gregor Mendel

Austria 1822–1884

flies that appeared in Morgan's cultures was one very dark fly which is called ebony, and a dark gray one called sooty. The hybrids were intermediate in pigmentation. When these were bred together there were segregated not merely the sooty and ebony types but also several grades of gray lying between. Nevertheless, it was possible to sort these intermediates in a way that showed a reappearance of ancestral traits in the Mendelian 3:1 ratio.

Extracted Pure Lines

Further experiments with the third and later generations, carried on by Mendel, and in more recent times by many investigators in all parts of the world, reveal a certain uniformity in the appearance of the alternative traits in successive generations. This uniformity can be stated in a simple mathematical formula, pointing to a uniform operation of some mechanism in the reproductive process. It is found, for example, in the case of the peas, that the recessive type (green seed) which reappears in the second generation is just as " pure " as the grandparent from which the type is derived. The offspring of such an individual will never include yellows unless at some point in the line there is again a crossing with the dominant type. That is to say, whereas a pure type can give rise only to its own kind of individuals hybrids can give rise to both kinds. The practical difficulty has always come from the fact that, because of dominance, it has been impossible to distinguish by appearance the pure dominant from the hybrid dominant (see Fig. 86).

The " phenotype " proclaims the presence of one of a pair of ancestral traits, but not the presence of the other. Breeding exposes the fact that the hybrid individual has both hereditary capacities and that it is genotypically different from the dominant parental form which it resembles. A pure dominant or a pure recessive derived after segregation from hybrid parents is called an " extracted " individual. Every recessive individual derived from hybrid parentage

remains pure and is called an extracted recessive. Of the dominants derived from hybrid parents, one-third are also pure and are called extracted dominants.

Combinations of Characters

Each individual plant or animal presents of course a multitude of characteristics. Mendel went back to find out what happens to the different traits, while his experiments with respect to one selected pair of characters were giving the uniform appearance of dominance, segregation and extraction of ancestral types. He conducted another series of experiments in which *two pairs* of contrasting traits were taken into consideration — for example, tallness and seed color, or seed color and smoothness of seed coat. These experiments showed that each pair of contrasting characters produced its dominance in the first hybrid generation and its segregations in the following hybrid generation, quite independently of the other pair. Thus a tall yellow-seeded plant crossed with a dwarf green-seeded plant would yield a hybrid generation in which all the plants were tall and all yellow-seeded, that is, dominant for both characters (Fig. 62).

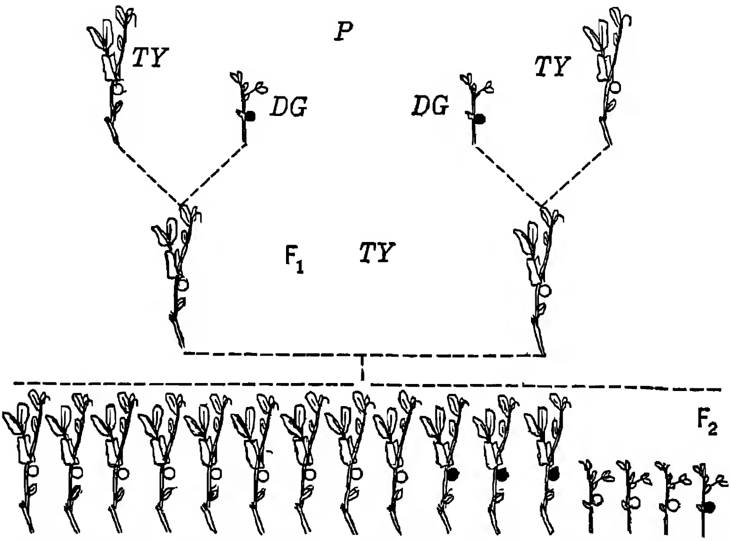
In the following generation, produced by self-fertilizing these hybrids, there was segregation for each trait studied. That is, the plants appeared in the ratio of three talls to one dwarf. There were also three yellow-seeded to one green-seeded. There were, however, new *combinations*, for four distinct types were present, namely,

(1) tall yellow-seeded,
(2) tall green-seeded,
(3) dwarf yellow-seeded, and
(4) dwarf green-seeded.

Recombinations have been found by many investigators to hold in animals as well as in plants. Among guinea pigs and rabbits, for example, pigmentation is dominant

over albinism, and short hair is dominant as against long hair. The mating of a black short-haired animal with a long-haired albino will yield in the first hybrid generation short-haired black animals resembling in both traits one of the parents — that is, the dominant (see Fig. 63).

The descendants of a hybrid pair that show recessive characters continue to produce "pure" offspring, notwithstanding their hybrid parentage and their mixed ancestry.



9 Tall yellow + 3 Tall green + 3 Dwarf yellow + 1 Dwarf green

FIG. 62. HEREDITY OF TWO PAIRS OF CONTRASTING CHARACTERS

On mating a tall plant bearing yellow seeds (*TY*) with a dwarf plant bearing green seeds (*DG*), the hybrids resulting (F_1) all resemble one parent, *TY*, since tallness and yellow-seededness are both dominant over their alternatives Although these hybrid plants resemble their dominant parents in both characters, they do not breed true on mating they yield in the next generation (F_2) four distinct kinds of individuals, showing the four possible combinations of size and seed color The proportions in which these four combinations appear are also significant Out of every sixteen plants there are 9 tall yellow-seeded, like their hybrid parents (that is, dominant in both characters), 1 dwarf green seeded, like the lost grandparents (that is, recessive for both characters); and three each of tall green-seeded and dwarf yellow-seeded (that is, dominant for one trait and recessive for the other) The classical 3:1 ratio is perhaps concealed among these large numbers, but note that among all the green-seeded plants as well as among all the yellow-seeded ones there are three talls to one short. Similarly, among all the tall plants as well as among all the dwarfs there are three yellows to one green.

That is to say, if the dwarf green-seeded plants (for example, the last in F_2 of Fig. 62) were self-fertilized they would produce only dwarf green-seeded progeny. In the case of the rodents, the white long-haired individuals which did not resemble either of the parents (who were black-haired hybrids) would always breed true for long hair and white coat. Similarly the yellow-seeded dwarf would breed true for the dwarf character, but not necessarily for the yellow seeds; and the tall green-seeded plants would breed true, when self-fertilized, for the green color of the seed but not necessarily for tallness.

Tri-hybrid

Mendel continued his experiments with three traits — for example, tallness, color of seed, and roundness or angularity of the seed. In such crossings for three characters, the law of dominance still held. That is, in the hybrid generation all the plants were tall, all produced yellow seeds and all produced roundish or smooth seeds. On allowing these hybrid plants, which presented the dominant character of all the pairs studied, to fertilize themselves there was produced a generation in which each pair of characters was segregated in the usual ratio of three dominants to one recessive. Thus there were:

3 talls to 1 dwarf,
3 yellow-seeded to 1 green-seeded,
3 smooth-seeded to 1 wrinkle-seeded.

But there was further to be observed every possible combination of three pairs of characters, namely eight (2^3). Furthermore, these new combinations appeared in definite proportions, which can be stated in a simple mathematical formula. The actual constitution of such a segregated hybrid generation for the three pairs of characters in question is as follows for 64 individuals, the smallest number that can show all the combinations:

TALL	SMOOTH	YELLOW	27	(Dominant for all traits)
TALL	SMOOTH	green	9	(Dominant for two, recessive for one)
TALL	wrinkled	YELLOW	9	
dwarf	SMOOTH	YELLOW	9	
TALL	wrinkled	green	3	(Dominant for one, recessive for two)
dwarf	wrinkled	YELLOW	3	
dwarf	SMOOTH	green	3	
dwarf	wrinkled	green	1	(Recessive for all traits)

Such recombinations of traits has been demonstrated for hundreds of characters in many different species of plants and animals (Fig. 63).

Mendel's Explanation

The segregation of traits in the offspring of self-fertilized hybrids give mathematically consistent results. This fact led Mendel to the conclusion that *whatever it is that determines the appearance of a character becomes segregated in the formation of the germ cells.* He assumed, for example, that the egg cells from a yellow-seeded parent carry something that determines yellowness in the seed of the offspring; and that the sperm of a yellow-seeded parent carries something that determines yellowness. And similarly for green seed and for other characters. When the hybrids produce eggs and sperms, each germ cell carries only one determiner. There are therefore two kinds of egg cells and two kinds of sperm cells, one kind of each carrying the determiner for the dominant trait and one kind carrying the determiner for the recessive trait (see Fig. 64). These assumptions would correspond with the actual results of the breeding experiments.

As a result of his years of experimentation Mendel concluded:

1. Each pair of contrasting characters in a plant is produced by a pair of alternative determiners, and each unit character is independent of other characters. For example, seed color is inherited independently of height of the plant, shape of the seed, and so on.

FIG. 63. THE PRINCIPLE OF INDEPENDENT ASSORTMENT

Pigmentation in guinea pigs is dominant over albinism; short hair is dominant over long hair, and rough coat is dominant over smooth coat When two "pure" individuals like those shown are mated, the offspring will all be like the lower animal, but with a rough coat On mating the hybrids together in sufficient numbers, the segregation will result in producing every possible combination of these three sets of characters: dark-short-rough, dark-short-smooth, dark-long-rough, dark-long-smooth, white-short-rough, white-short-smooth, white-long-rough; white-long-smooth — eight in all (2^3). The proportions will be such that *for each pair of contrasted characters* there will be three dominants to one recessive From photographs by Professor W E Castle; in Gruenberg, Elementary Biology, published by Ginn & Company

2. Of each pair of contrasting characters, one is dominant and the other recessive. He supposed that the presence of the determiner for dominant inhibits the development of the recessive.

3. Each germ cell contains only one *or* the other determiner for a given pair of contrasting characters. By the "purity of the gametes" Mendel meant that any given egg or sperm could determine the development of *either* the dominant *or* the recessive, although the hybrid parent body bearing the germ cells had the capacity to produce two kinds of "pure" germs.

Of these three principles the second and third have been confirmed by later researches. While the modern student

would qualify the statement of these principles somewhat, he would go farther than Mendel and point his finger more precisely to just what it is in the germ cells that brings about the observed results. As to the principle of unit character,

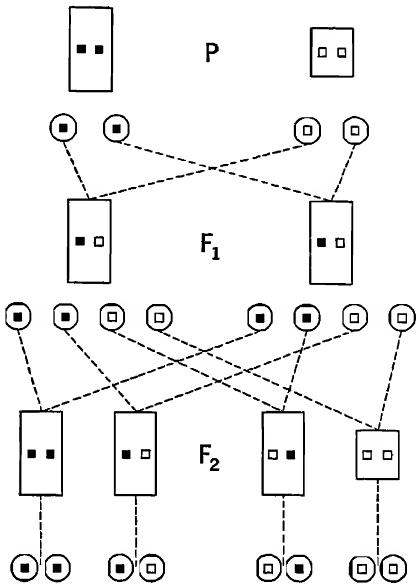


FIG. 64. MENDEL'S EXPLANATION OF SEGREGATION

Two parents, P, that differ with respect to a given character (here represented by difference in size) differ also as to the germ cells (small circles) which they produce The pure recessive can produce only one kind of gamete, carrying a determiner for the recessive trait The pure dominant likewise produces but one kind of gamete, carrying a determiner for the dominant trait Now the hybrid, F_1, although resembling the dominant parent, has the capacity to produce two types of gametes that is, each gamete is "pure" for one or the other of the contrasting characters, regardless of whether it is produced in a pure bred individual or in a hybrid The offspring of the hybrids, F_2, results from the four possible combinations of the two types of gametes (1) egg and sperm both dominant, (2) egg and sperm both recessive, (3) egg dominant and sperm recessive; (4) egg recessive and sperm dominant This assumption of Mendel's agrees with the experimental facts the offspring of hybrids are one recessive for three dominants, only one of the three, however, being "pure" in its constitution, as shown by the results of further breeding

it has been shown that while Mendel was right in view of the limited number of experiments he carried out, both the observed constitution of the germ cells and the observed transmission of hereditary traits would make this assumption of

independent determiners quite untenable for *all* unit characters. We know now as a matter of fact that each "determiner" produces more than one effect. The students had simply described the most noticeable characteristic, overlooking many others. Among the sweet peas, for example, the petal called the standard is erect in purple flowers and drooping in white flowers. In the garden pea round seeds are associated with tendrils on the leaves, and colored seed coats with purple flowers. On the other hand, many traits of plants and animals that seem to be simple characters have been found to depend for their manifestation upon two or more independent factors.

Determiners and Factors

Mendel's assumption of determiners present in the germ cells was in complete accord with all of his findings, and, as we shall see, with certain fundamental facts in the structure and behavior of the germ cells. It was his good fortune that he selected for his experiments the characters of the garden pea with which he actually worked, since there are other sets of contrasting characters that he might have chosen and that would have led him hopelessly astray. The relatively simple cases did yield the significant mathematical formulas that unlocked the more complex situations.

William Bateson and R. C. Punnett in England found two strains of sweet peas with white flowers which were indistinguishable from any of their outward characters. The microscope showed one of them to have a longer pollen grain than the other. After crossing these two varieties, all of the succeeding generation blossomed out in gay purple flowers. This unexpected result was looked upon as a case of reversion or throw-back, since the wild Sicilian sweet peas from which the cultivated varieties had been derived have such purple flowers. Further breeding resulted in a distribution of the segregated forms into two groups, in the proportion of nine colored to seven white. If we assume that

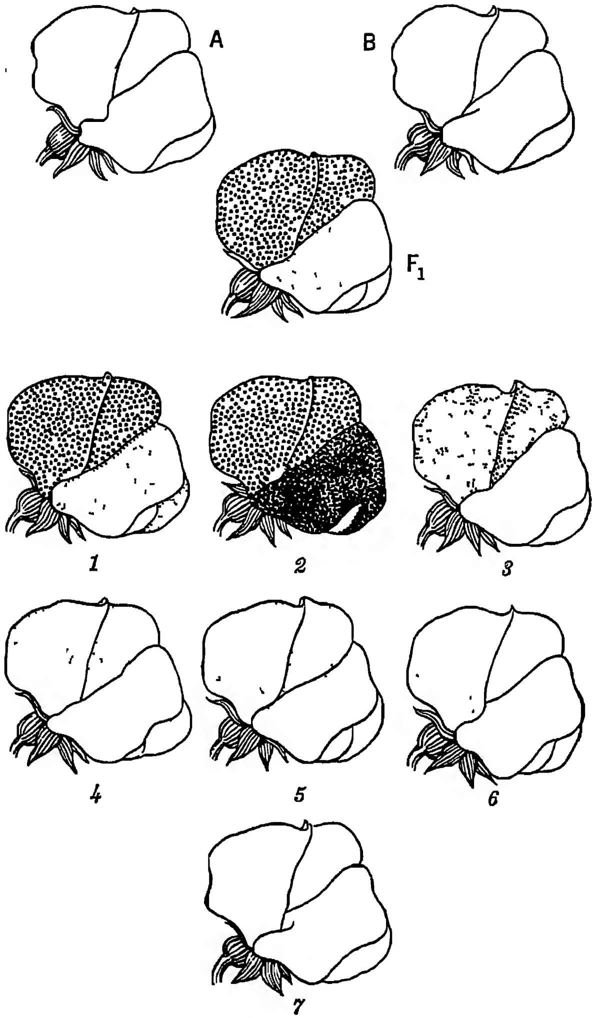


FIG 65. FACTORS IN HEREDITY

Two "pure" strains of white-flowered sweet peas were crossed, A, B. The hybrids, F_1, were all brightly colored purple and blue flowers. When in-bred these hybrids gave rise to flowers with various combinations of purple, blue, red, pink, white, including pure white flowers 1–7. It is possible to show experimentally that the appearance of any color at all in these flowers depends upon the presence of both a color base and a color developer, which are inherited independently A carries one factor into the combination and B carries the other. If both factors are present, the particular combination of colors, 1–6, is determined by the presence of additional factors, each of which may be transmitted independently in Mendelian fashion After Punnett

the color formation depends upon the action of a ferment or *enzyme* upon a special substance, the *chromogen,* and that each strain had *one* of these factors in its hereditary constitution *but not the other,* there would be no color in the flowers of the pure strains. The hybrid resulting from the crossing, having both factors, produces purple flowers. In the following generation, segregation takes place and the ratio of 9:7 suggests a modified 9:3:3:1, indicative of a hybrid in which *two* alternative characters are involved (see Fig. 65).

In Bateson's experiments, the hybrid purple-flowered strain broke up in the next generation into forms showing seven different color combinations, including the pure white. The breeding tests led to the discovery that there were five distinct factors involved in determining the appearance of the flower. Professor W. E. Castle of Harvard, studying the coat colors of rabbits, found eight different factors involved; and other workers later found a similar series of seven factors related to the production of coat color in mice.

The use of the concept *factors* in place of *determiners* has simplified the interpretation of many hybridizations. This idea agrees (1) with the fact that in many cases there appear graded series between the two parental types, instead of the sharp separations which Mendel found; (2) with the fact that each variable in the germ affects more than one character; and (3) with the fact that each character of the plant or animal may be influenced by several elements in the germinal plasm. A familiar example of a character that is influenced by several factors is stature. Experiments with wheat and other grains, as well as with animals, show that the distribution of intermediate types into numerous graded groups is in perfect accord with the idea that the transmission of this character is determined by several factors.

The Germ Cells

In the higher plants and animals the new individual arises from a union of two cells, the egg and the sperm,

detached from the body of the parents. It is in these germ cells or gametes that we should seek the mechanism that brings about the continuity of species. The progeny is like the parents because of something in the germ cell. We have already seen (page 124) that the fertilized egg divides into two cells and that each of these divides again in the initial stages of the individual's development. Cell division is a normal process found in all kinds of plant and animal cells.

Careful study of the cell structure at the time of division shows peculiar changes taking place in the kernel or nucleus of the cell. The nucleus consists of several different substances which can be discerned under the microscope after suitable treatment with various chemicals and stains. Just before the division there appears in the nucleus of the cell a tangle of substance called chromatin, which divides up into a definite number of pieces called chromosomes. The number of chromosomes is the same in all the cells of the body, but it is not the same in all species of plants and animals. The fruit fly, for example, has four pairs or eight distinct chromosomes. The cells of a wheat plant show eight pairs or sixteen chromosomes. In man, potatoes, and onions the number is twenty-four pairs or forty-eight chromosomes.

During the process of cell-division each chromosome splits lengthwise and the two halves move to the opposite poles of the nucleus (see Fig. 66). The two groups of chromosomes assemble and the several pieces in each gradually merge together into a new nucleus. A separating partition is often formed between the nuclei and thus two new cells are established. This is in general the procedure in all kinds of plant and animal cells.

A suggestion had long ago been made that the complicated movements of the chromosomes in preparation for cell division and the precise separation of each chromosome into two identical halves must have some significance in transmitting the organism's characters from cell to cell in the formation of the body, and eventually from parent to offspring in the formation of new germ cells. The confirma-

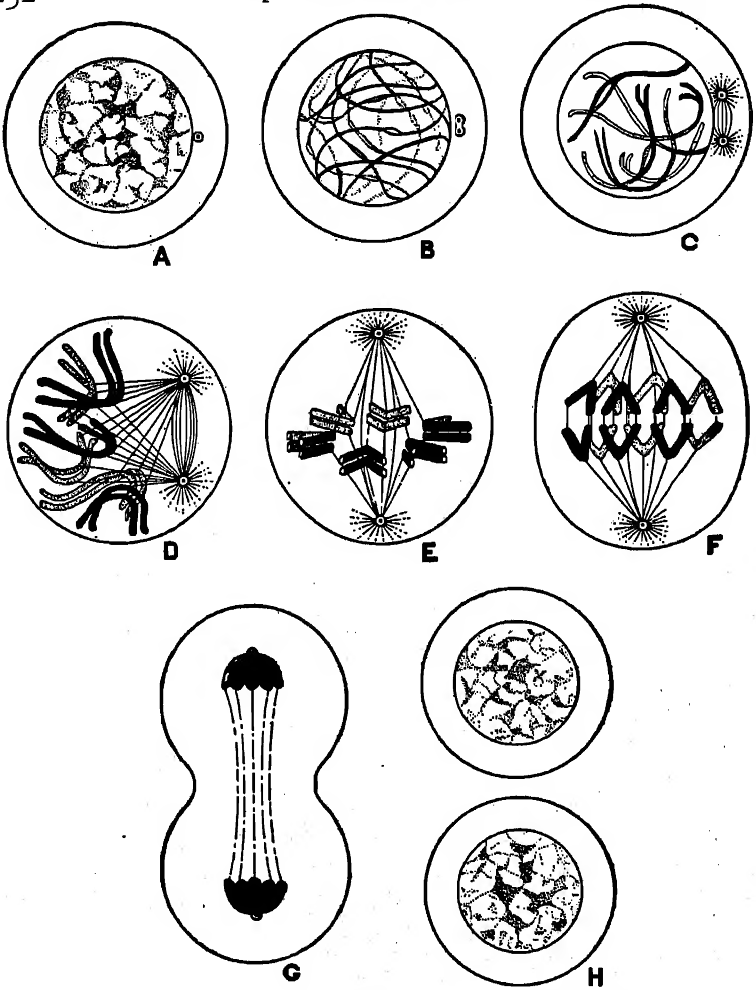


FIG. 66. THE CHROMOSOMES IN CELL DIVISION

In the resting stage, *A*, chromosomes are not distinguishable. Activity begins by the chromatin material taking form and the centrosome at the side of the nucleus dividing into two, *B*. The centrosomes start moving toward opposite poles, *C*, while the chromatin fiber breaks up into a definite number of chromosomes (six pairs in the diagram). The chromosomes appear to be attached to the "spindle fibres" connected with the centrosomes, *D*, and the nuclear membrane disappears. The chromosomes arrange themselves in pairs about the equatorial plane, *E*, the centrosomes occupying opposite poles. The two chromosomes of each pair move toward opposite poles, *F*. The chromosomes in the two opposite groups fuse together, *G*; and two new nuclei are constituted, *H*. (Adapted from Agar's Cytology, copyright by Macmillan & Company, Ltd.; from Babcock and Clausen, Genetics in Relation to Agriculture, published by McGraw-Hill Book Company.)

tion of this suggestion has come in recent years through a large number of experimental studies.

Chromosome Reduction

When a germ cell is formed the cells of the ovary or spermary that are to form gametes divide at first in the way

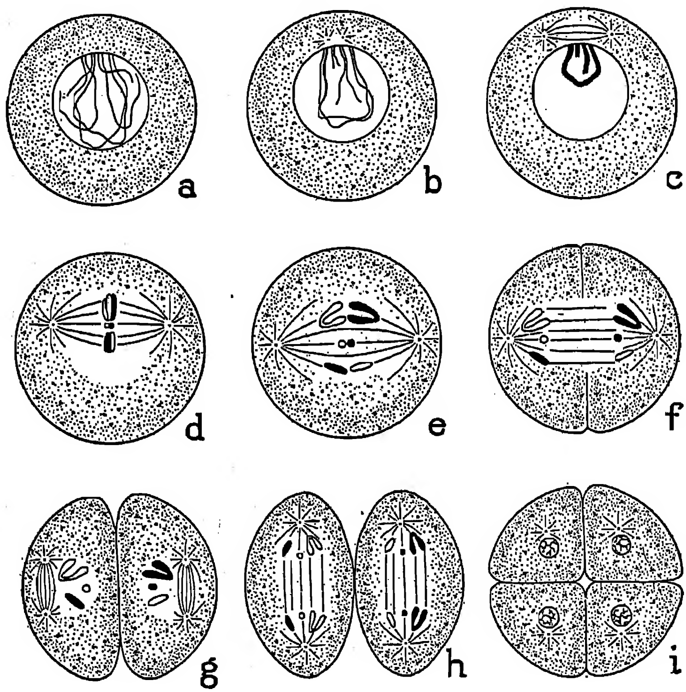
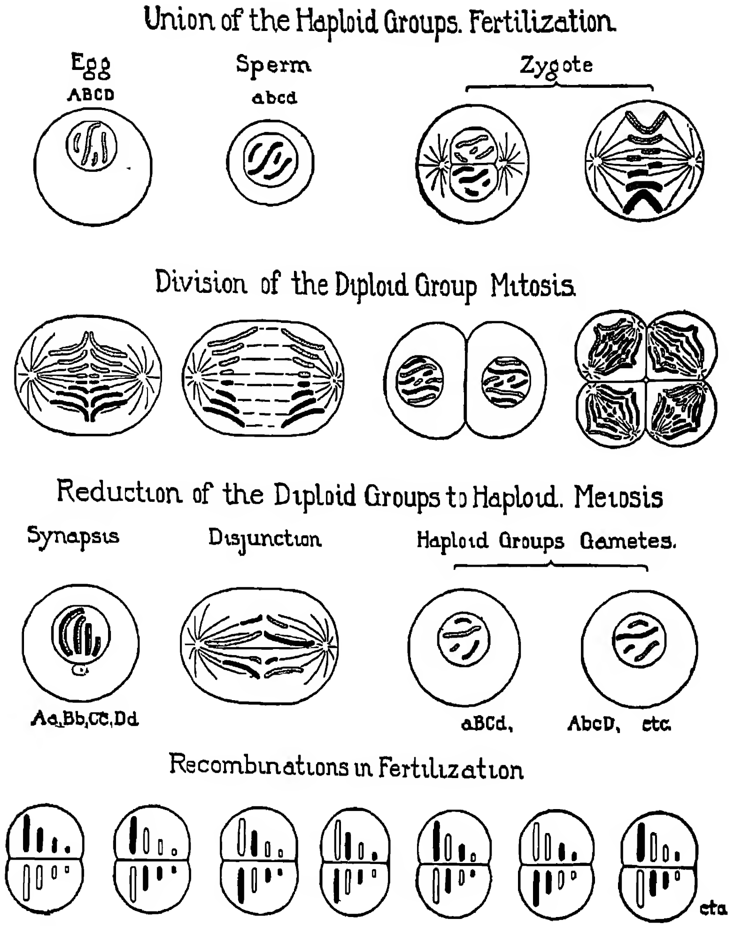


FIG 67. THE RIPENING OF GERM CELLS

The chromosome material passes from a diffused, or at least indistinguishable, stage into a tangle or thread, a, b, that becomes thickened, c, and divides into a definite number of paired chromosomes (three are here shown for the sake of simplicity), d. Each pair of chromosomes divides, one member moving to one pole and one to the opposite pole, e, f. The three chromosomes derived from the father are shown in black, those from the mother in white. The distribution of the chromosomes to the two poles is quite random, but one of each pair goes to each pole, and two daughter cells are formed, g. Each chromosome then splits lengthwise and the two halves become separated, h, the two cells becoming four, i. Each of these cells now contains one half the *number* of chromosomes of the original cell, a-d, and one fourth of the chromosome material. From Morgan, The Theory of the Gene, published by Yale University Press.



SUMMARY OF CHROMOSOME BEHAVIOR AND RELATIONSHIP

In the germ cells, egg and sperm, the chromosomes are not paired The four shown for illustration are distinguished by relative lengths. The maternal elements are shown in outline and identified as A, B, C, D; and the paternal in black, as a, b, c, d On fertilization the zygote acquires the double or diploid number of chromosomes — that is, it now has four *pairs*, one of each pair from the mother (egg) and one from the father (sperm). The constitution of the new individual is, Aa, Bb, Cc, Dd In the course of normal cell division (Mitosis) each member of each pair divides into two, and each daughter cell has a full complement of chromosomes, continuing the composition of the zygote When new germ cells are being formed the diploid number is again *reduced* (Meiosis), the members of each pair going to two different cells — *but the separation is random* Thus, the two new gametes illustrated show the combinations aBCd and AbcD, sixteen different combinations being possible for four chromosomes (4^2) — compare Fig. 68 When fertilization takes place, with 16 types of sperms and 16 types of eggs, mating is random and there are 256 possible combinations (16^2), of which seven are shown From Wilson, The Cell in Heredity and Development, published by The Macmillan Company.

already described for body cells. The final division, however, results in producing cells that have only one-half the usual number of chromosomes (see Fig. 67). Later, when fertilization takes place, the chromosomes of the sperm and those of the egg cell combine and start the new individual with a full complement of chromosomes. The process of fertilization thus brings into the individual's make-up germinal material — or more specifically chromosome material — from each parent. When the germ cells are being formed, it is the *pairs* of chromosomes that break up. Each sperm cell and each egg cell may therefore get a different complement of chromosomes. As a result the individuals of the following generation will have entirely new combinations of chromosomes in the cells. The uniting of chromosomes from the two germ cells into pairs, and the subsequent random separation of the members of each pair in the production of new germ cells, furnish a mechanism in perfect accord with Mendelian inheritance. These facts serve not only to explain segregation in the proportions observed, but also to prophesy new combinations of characters in the making of new hybrids (see page 256 and Fig. 68).

Individuality of the Chromosomes

The chromosomes had been for a long time recognized as the carriers of heredity. They are, however, very few in number — few, that is, compared with the number of characteristics that make up an individual, even a small individual like a fruit fly. It is therefore necessary to consider what connection there is between the numerous inherited traits and the few chromosomes. The intensive work on these problems with the fruit fly *Drosophila* has shown first of all that, corresponding with the four pairs of chromosomes, there are four sets of inherited pairs of characters. In the study of hundreds of character pairs and of mutational forms, it became apparent that certain characters appear together more often than others, and by grouping these characters it was

finally revealed that there are four distinct groups. To show that these four groups of characters correspond to the four pairs of chromosomes was not so simple a matter. A clue

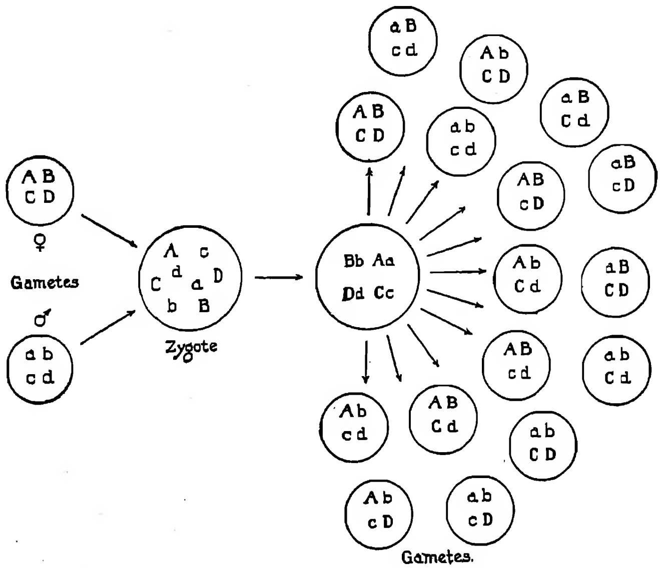


FIG. 68. RECOMBINATIONS WITH INDEPENDENT ASSORTMENT

Let us assume four chromosomes in the germ cells of a plant or animal — A, B, C, D in the egg and a, b, c, d in the sperm. On fertilization the zygote is formed with four *pairs* of chromosomes, Aa, Bb, Cc, Dd. This represents the constitution of the new individual. If the capital and small letters of each pair stand for alternative characters in the parents, the symbols for the zygote represent the constitution of the hybrid. When new gametes are being formed the chromosomes of each pair become segregated in the course of the reduction division — that is, each germ cell has only four chromosomes instead of four pairs of chromosomes. There are thus sixteen combinations possible (4^2). Only one of the sixteen derives all of its germinal material from the mother (ABCD) and only one from the father (abcd). These theoretically possible recombinations are in perfect agreement with the results of Mendelian segregation. From Wilson, The Cell in Heredity and Development, published by The Macmillan Company.

which led to the unraveling of this complicated problem was found after it was learned that the sex of the individual is determined by the chromosomes and that certain

characteristics are always associated with the presence of sex-determining chromosomes.

Inheriting Sex

To say that the individual inherits his sex is today commonplace among biologists. To those who are not acquainted with the underlying facts it still sounds absurd. From which of the two parents does the individual inherit his or her sex? It will no doubt add to the incredibility of the statement to say that in some kinds of animals sex is inherited from the

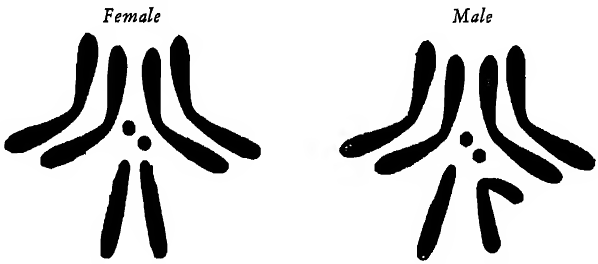


FIG. 69 THE CHROMOSOMES OF THE FRUIT FLY

There are two pairs of large chromosomes, somewhat bent, one pair of very small ones, and one pair of intermediate, rod-shaped chromosomes, making four pairs in all. This last pair differs in the two sexes, the female having two that appear to be alike, whereas in the male one is a little longer and bent at the end After Bridges

father, whereas in other species it is inherited from the mother. But that is indeed the case.

In the female *Drosophila* there are four pairs of chromosomes; and the members of each pair are indistinguishable (Fig. 69). In the cells of the male, the chromosomes are just the same except that one of the medium-sized pair is longer than the other and bent near the end. This difference between the sexes is constant. There is something about these chromosomes that determines the sex of the developing individual. The straight chromosome has been called the X chromosome, and the bent one the Y chromosome. In the presence of XX, the fly is a female; in the presence of XY, it is a male.

When gametes are being formed in the mature insect, the reduction division, which cuts in half the number of chromosomes in a germ cell, results in producing two similar egg cells but two different sperm cells (see Fig. 70). Sex determination through chromosomes has been found to hold for other species. In man the actual number of chromosomes has been given as 24 pairs or 48. One of these pairs, however, seems to be different in the two sexes. There is, in fact, an apparent reduction of one of these pairs in the male, almost to the vanishing point, so that cells of the male show only 47 chromosomes distinctly, as against 48 in the female (Fig. 71). The reduction division that brings about the formation of eggs cells thus produces gametes containing each 24 chromosomes, whereas the reduction division leading to the formation of sperm cells is always unequal and yields two kinds of sperm cells, one with 24 chromosomes and one with 23 chromosomes (and the very small one which is sometimes overlooked by the observer). If an egg cell is fertilized by one of the former there results

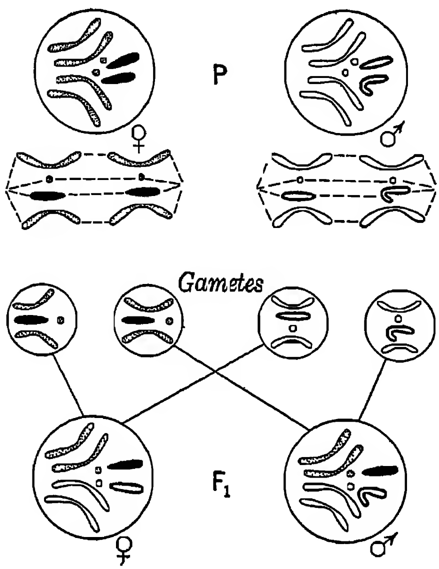


FIG. 70. REDUCTION DIVISION IN RELATION TO SEX DETERMINATION

The chromosomes of the male (light) parent (P) differ from those of the female parent (dark) in the form of the Y chromosome As gametes are formed, one of each pair of the X chromosomes (black) goes to each egg In the formation of sperms, however, half get the X chromosome and half get the Y chromosome there is only one kind of egg, but there are two kinds of sperms In the following generation, F_1, the sperms containing the X chromosomes give rise to females, and those containing the Y chromosomes give rise to males Both males and females of this generation, however, derive half the chromosomes from the father and half from the mother.

a female; if fertilized by one of the latter a male individual develops.

This type of sex determination, in which there are two kinds of sperm cells (X and Y, or X and O) and one kind of egg cell (X), has been reported for most of the insects, outside of moths and butterflies, for the sea urchins, for many round worms, in the horse, and in the opossum. The indica-

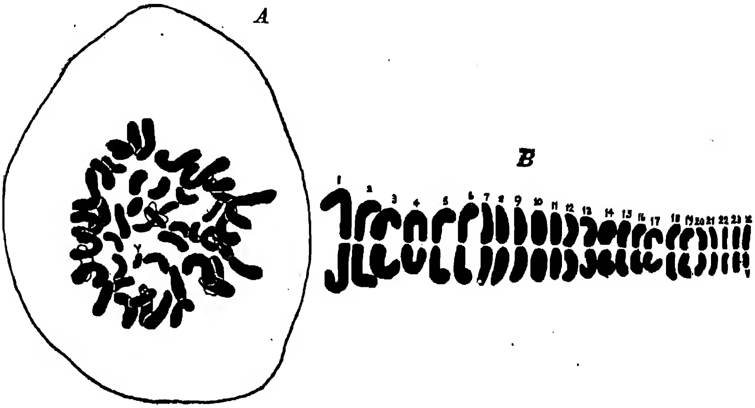


FIG. 71. CHROMOSOMES IN MAN

The forty-eight chromosomes are shown distinct but crowded together in the cell that is to give rise to sperm-cells, at *A*. The smallest chromosome is shown at Y. The twenty-four pairs are spread out, *B*, showing the two sex chromosomes, X and Y, different in size. After Painter, from Conklin, Heredity and Environment in the Development of Man, published by Princeton University Press.

tions point to the guinea pig and most of the bony fishes as having also this type of sex-determining mechanism.

Among birds the relation of chromosomes to sex determination is somewhat different. In these animals the study of the chromosomes in the females shows one pair to consist of a large and a small unit, whereas the cells of the males have two equal chromosomes for the corresponding pair (Fig. 72). The hen therefore produces two kinds of eggs, one containing the large chromosome of this particular pair, called the Z, and the other containing the small member, called W. The male, on the other hand, produces only one kind of germ cells, each sperm containing one Z chromo-

some. In moths and butterflies a similar mechanism seems to operate.

The XX-XY (or XX-XO) form of sex determination, in which there are two kinds of sperm cells, is found also among many plants. In some animals there is no distinct sex chromosome, but a portion of one of the other chromosomes (called autosomes) acts like an X. Among bees,

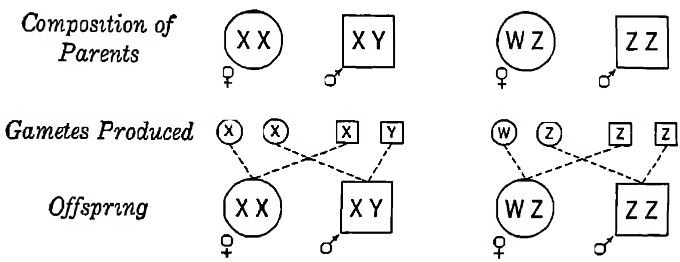


FIG. 72. TWO TYPES OF SEX DETERMINATION

Each individual, whether male (large square) or female (large circle), arises from the fusion of two gametes, an egg (small circle) and a sperm (small square) The inheritance of sex cannot, therefore, mean a direct transfer of the sex of one of the parents to the offspring. Among certain plants and animals each egg (small circles, X, X) may develop into *either* a male *or* a female, depending upon the kind of sperm cell with which it has combined (small squares X and Y) When two X chromosomes get into a fertilized egg the individual develops into a female, when only one X chromosome enters the combination, a male develops. In such cases sex is "determined by the sperm," whether the offspring is male (XY) or female (XX) Among birds and butterflies there are apparently two kinds of egg cells produced by the female (small circles W and Z), but only one kind of sperm cells by the male (small squares, Z, Z) When two Z chromosomes get into a fertilized egg, the resulting individual develops into a male; when only one Z chromosome comes into the combination the result is a female. In such cases the sex is "determined by the egg," whether the offspring is a male (ZZ) or a female (WZ).

wasps and ants, the males seem to consist of individuals that develop from unfertilized eggs, and therefore have one-half the number of chromosomes normally present in the females. The formation of sperm cells in this order of insects is exceptional, since there is no true reduction-division — the sperms contain the same number of chromosomes as the body cells of the male.

Sex-linked Characters

Among fruit flies there appears from time to time a male fly having white eyes in contrast to the usual dark red of the wild forms If such a white-eyed male is mated with the typical red-eyed female, all the offspring have red eyes. If these hybrids are interbred there will be a segregation among the progeny yielding three red-eyed offspring to one white-eyed. Strangely enough, however, white eyes occur only among the males. The explanation for this is found in assuming that the dominant eye-pigment determiner is here present in the X chromosome (Fig. 73). All the females have red eyes because each has at least one X chromosome containing the factor that results in pigment. Only half the males can have red eyes because only half of them can receive such an X chromosome, the others receiving the recessive X chromosome. This interpretation is confirmed by making a reciprocal cross (see Fig. 74).

Color-blindness

The association between special determiners and the sex chromosomes has been established for other characters and for other species, including man. Color-blindness of a certain type is found among human beings to be such a sex-linked character (see Fig. 75). Whatever it is that causes one to be color-blind seems to be carried by the X chromosome, of which the male has one and the female two. This does not mean that every X chromosome carries the determiner for this trait, but only that when it is present it is associated with the X chromosome. As in the white eye-color of the *Drosophila* male, the sex-linked character color-blindness in man is transmitted from the male through a daughter (who does not show it) to a grandson. Color-blind females are very rare; but such would occur in the offspring of a color-blind father whose wife was the daughter of a color-blind man (Fig. 76).

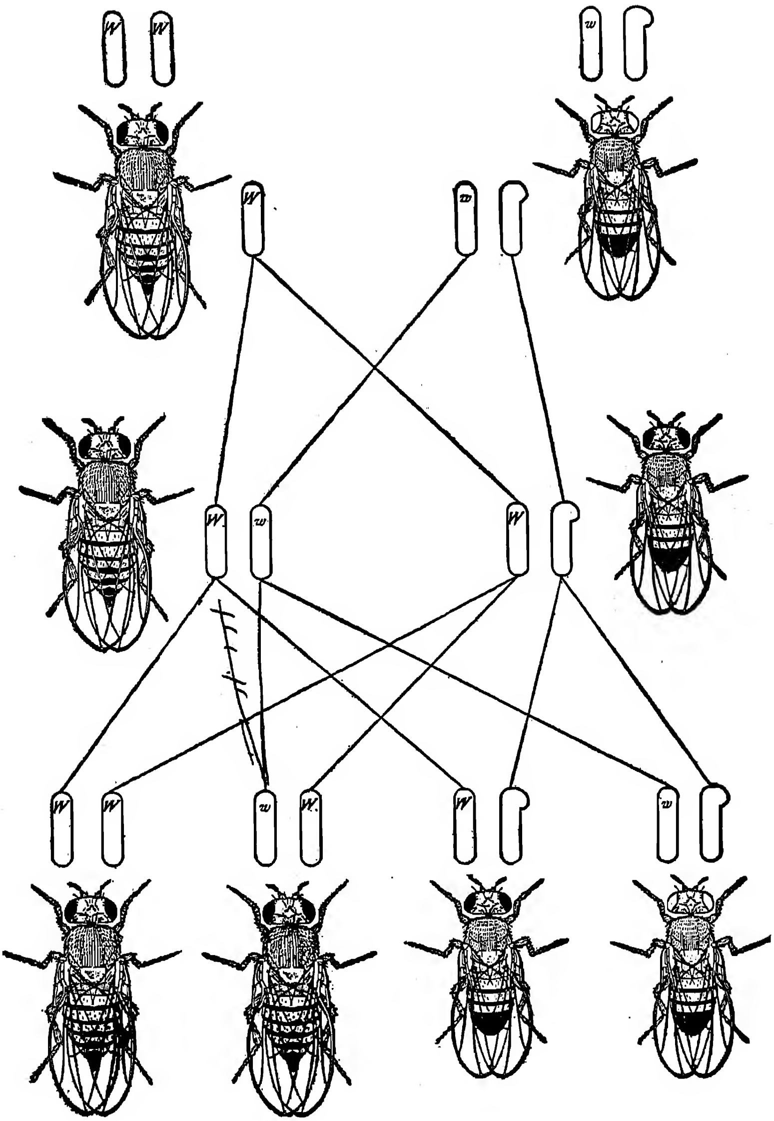


FIG. 73. SEX-LINKED INHERITANCE

In a cross between red-eyed female and white-eyed male, the results are explained if it is assumed that the eye pigment is determined by something (*W*) in the X chromosome. The female produces eggs containing X chromosomes, with each of which is associated the determiner, *W*. The male, however, produces two kinds of sperms, the X and Y, neither of which carries *W*. In the first hybrid generation every individual has red eyes because each has one X chromosome (with the pigment determiner, *W*) from the mother. In this generation both the males and the females produce two kinds of germ cells, one with the color determiner and one without; the sperm cells with the X chromosomes bear the color determiner, *W*. In the following generation there are four possible types of individuals, two types of males and two of females, but white eyes are found only among the males. From Morgan, The Physical Basis of Heredity, published by J. B. Lippincott Company.

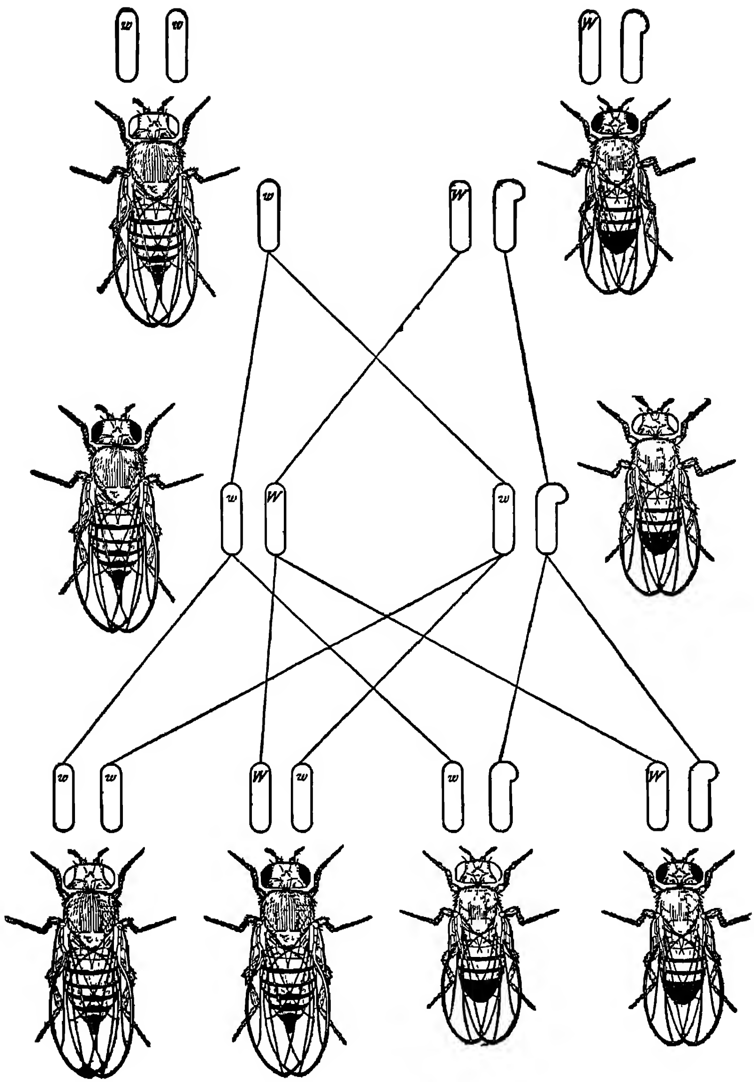


FIG. 74. CONFIRMATION OF THEORY OF SEX-LINKED INHERITANCE

The assumption that eye pigment is inherited among fruit flies as it is because the determiner is associated with the X chromosome is confirmed by crossing a white-eyed female with a red-eyed male. According to the theory the factor or determiner *W* would be carried by the single X chromosome of the male Instead of all of the F_1 generation having red eyes, only the females have, since the males derived their X chromosomes from the white-eyed (recessive) mother In the following generation (F_2) red and white eyes appear equally in both sexes The red-eyed male is always "hybrid" for eye color, according to this theory Consequently the F_1 has only red-eyed females and white-eyed males, just the reverse of the parental characters From Morgan, The Physical Basis of Heredity, published by J B Lippincott Company.

The "Knight's move" pattern of hereditary transmissions, now explained as resulting from a sex-linked determiner, has been observed for other characters. Notable among human beings is a certain type of "bleeding," due to

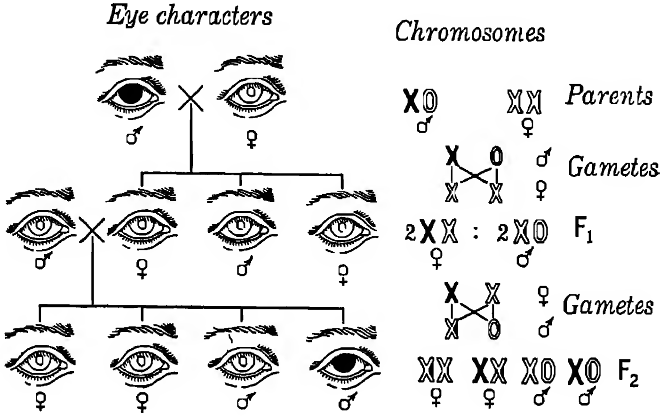


FIG. 75. INHERITANCE OF COLOR-BLINDNESS

The sex chromosomes in the male are represented by XO and those in the female by XX. The male produces two kinds of sperms, those with the X chromosome and those without, but all eggs contain one X chromosome There are therefore two possible sperm-egg combinations, which would theoretically occur in equal numbers, resulting in approximately equal numbers of males and females in the F_1 generation Assuming that color-blindness is determined by something in the X chromosome of the color-blind male, half of the sperms (those with the X chromosome) would carry the determiner for this character In the F_1 generation all of the females will carry this chromosome, but none of the males Females, however, do not show color-blindness if one of their X chromosomes is free from the determining element In this generation the males again produce two kinds of sperm cells, but neither can carry the determiner for color-blindness The females, however, produce two kinds of eggs, half of the X chromosome carrying the determiner for color-blindness There are therefore possible two kinds of males in the F_2 generation, those with and those without the affected chromosome But since the male exhibits color-blindness when carrying a single affected X chromosome, half the males are color-blind, and there are no color-blind females

a defective clotting of the blood. Like color-blindness this hæmophilia occurs in males and is transmitted through daughters (who do not exhibit the trait) to grandsons. Like color-blindness also, hæmophilia occurs in females only

when the character is present in both the father and the maternal grandfather.

Linkage and Cross-over

It is a fact that certain traits appear to be determined by something associated with a particular chromosome. It is a fact that pairs of alternative characters are not all independent of one another, as Mendel had supposed. These

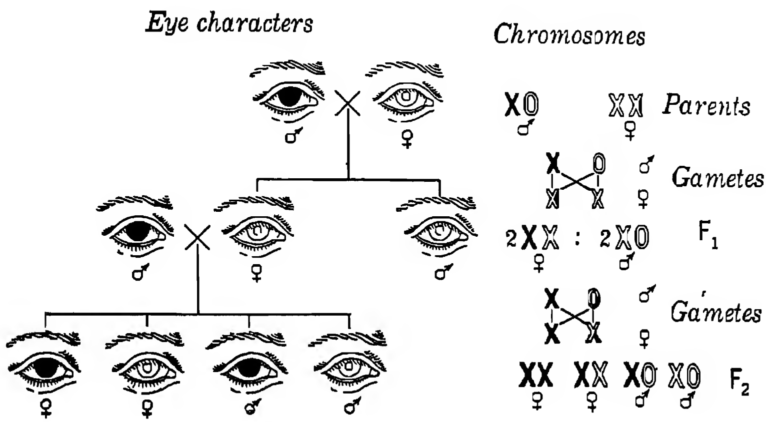


FIG. 76. COLOR-BLINDNESS IN A FEMALE

When color-blindness occurs in a female it seems to result from a meeting of two affected X chromosomes as follows. in the daughter of a color-blind male (female in F_1), carrying two X chromosomes of which only one is affected (that derived from the father), mates with a color-blind male, whose single X chromosome is also affected In the offspring, F_2, all the females get one X chromosome from the color-blind father, and one half of them get from the mother the affected X chromosome. The result is that one half the females in F_2 are color blind. One half the males are also color blind, but in their case the color-blindness is determined by the X chromosome of the normal mother (in F_1), not by the color-blindness of the father

two facts have led to the theory that each chromosome contains a series of determiners, called *genes* by Morgan, and that these genes occur in pairs — one in each of a pair of chromosomes. On this assumption we can explain why apparently unrelated characters generally occur together. Not only color-blindness and maleness, but, in the fruit fly, vari-

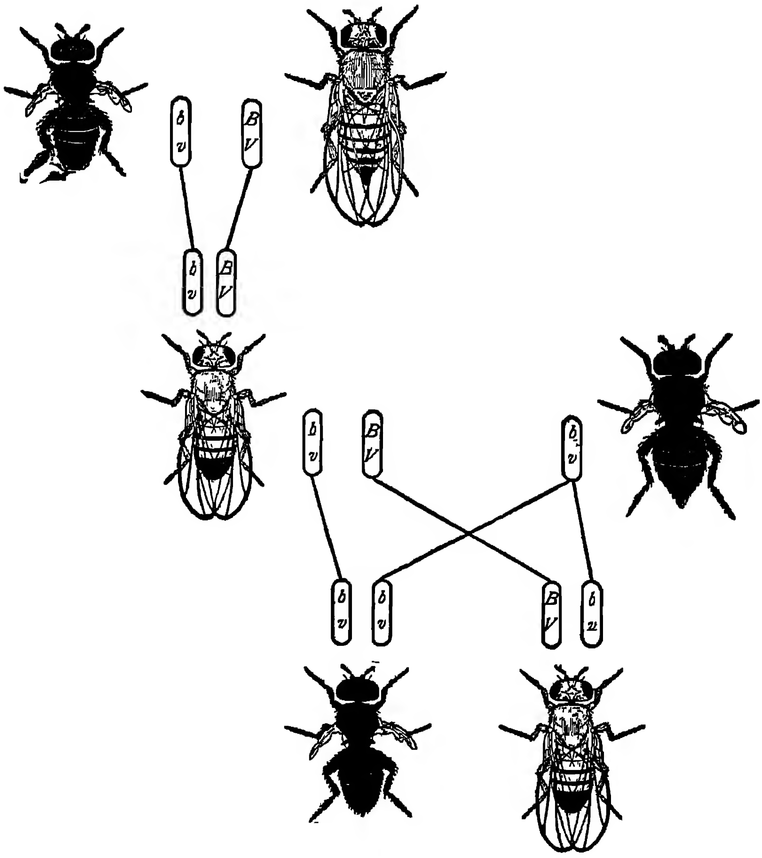


Fig 77. LINKAGE OF CHARACTERS IN FRUIT FLY

A male fruit fly having black body color and vestigial wings is mated to a normal wild female, that is, one with gray body color and long wings The offspring are all of the wild type, the mutation characters (black, vestigial) being recessive If now one of the hybrid males is mated to a black female with vestigial wings, we should expect, according to the theory of independent assortment of the various characters, that the following generation would show a new recombination of wing characters and body color We find instead that there are only two kinds of flies, similar to the two types of the grandparents. In other words, the characters that went into the cross together come out together From Morgan, The Physical Basis of Heredity, published by J. B Lippincott Company.

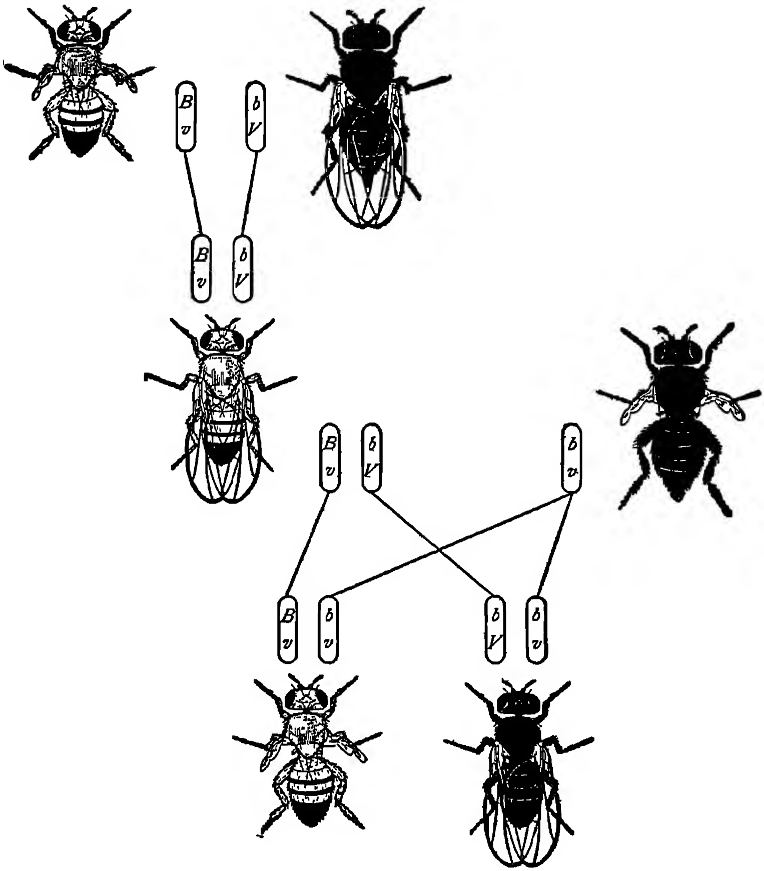


FIG. 78. LINKAGE SHOWN BY BACK-CROSS OF HYBRID

Black body color sometimes appears among fruit flies as a mutation, as does also the vestigial wing character. If two such mutants are crossed the offspring will resemble the wild type of fly, since gray body color and long wing are both dominant. If such a hybrid is now mated with a fly having both mutant characters, there will result two types of flies in the next generation (F_2), resembling the two single mutants That is, the characters that went into the combination together come out together If there were independent assortments there should result four types of flies Compare the result of the second mating with the first one shown in Figure 77. From Morgan, The Physical Basis of Heredity, published by J B. Lippincott Company.

ous characters of the eye, the wings, the legs, the abdomen, the hairs, and so on, seem to be linked together. Thus, in certain strains of flies, black body, vestigial wings and purple eyes go together (Fig. 77). Whether the particular characters studied are dominants or recessives, they seem to stay together after segregation, instead of forming entirely new combinations (Fig. 78). As the chromosomes divide preparatory to cell division the genes making up one chromosome are split lengthwise: each cell of the body therefore has a gene corresponding to another particular gene in each of the other cells. When germ cells are about to be formed, the two members of each pair of chromosomes become separated, one going to each of the resulting germ cells and carrying its set of genes. This corresponds to the close association of various characters in distinct groups. Such an association of characters is called a linkage. Linkage is supposed to be due to the adhesion of neighboring genes. Studies have shown linkage of three, four or more characters.

Linkage, however, is not absolute. In the course of experiments in heredity, certain groups of characters usually travel together from generation to generation. Sometimes, however, they become separated. Yellow wings and white eyes are recessive in the fruit flies; and experiments have shown these two characters to be closely linked. If a male fly with these characters is mated with a wild female, having red eyes and gray wings, all the offspring will have gray wings and red eyes — the dominant characters (Fig. 79). If one of the hybrid females is now mated with a male of the father type, that is, one having recessive yellow wings and white eyes, there will be produced four kinds of offspring. If there were perfect linkage we should expect, in accordance with Mendelian ratios, two types of offspring — one having both eye and wing characters dominant (red and gray) and the other having both characters recessive (white eye and yellow wing). On the other hand, if there were no linkage the four types would appear in equal proportions (Fig. 80). In actual experience these four types occur in the ratio of 99 grandparent types

to one of the transposed traits — that is, 99 per cent of the wild type red-gray and mutant white-yellow, and 1 per cent of white-gray and red-yellow. In other words, the linkage groups are broken up in 1 per cent of the cases. If the same characters are introduced into a cross in a different combination, and the dominant hybrid is again crossed back to a recessive, the four types will again appear, and again the grandparent types will be represented by 99 per cent of the progeny, and the cross-overs by 1 per cent. These facts are interpreted as showing a breaking up of the linkage group, by the exchange of genes between the two members of a pair of chromosomes.

Chromosome Maps

Such cross-overs have been found to occur for many pairs of characters, but the percentages are not always the same, ranging from 1–99 to about 50–50, at which point the effect is the same as independent unit characters of Mendel.

The theory of the gene assumes that the genes are arranged along the length of the chromosome. Before the two chromosomes in a pair separate (at the time germ cells are formed) they first come together, and in many cells they are seen to become twisted about each other. It is supposed that in this situation there is an opportunity for the two corresponding genes at one point or another to cling together and cause a transposition of portions of the chromosome (Fig. 81). Assuming that this is the behavior of the chromosomes and genes, that explains the observed facts of cross-over in breeding.

Morgan and his associates have constructed a "map" of the fruit fly chromosome (Fig. 82). This is based on the facts of linkage and grouping of pairs of contrasting characters or allelomorphs, on the facts of cross-over, and on the relative proportions of cross-over, for various pairs of linked characters, or the frequency with which the various linkages are broken up.

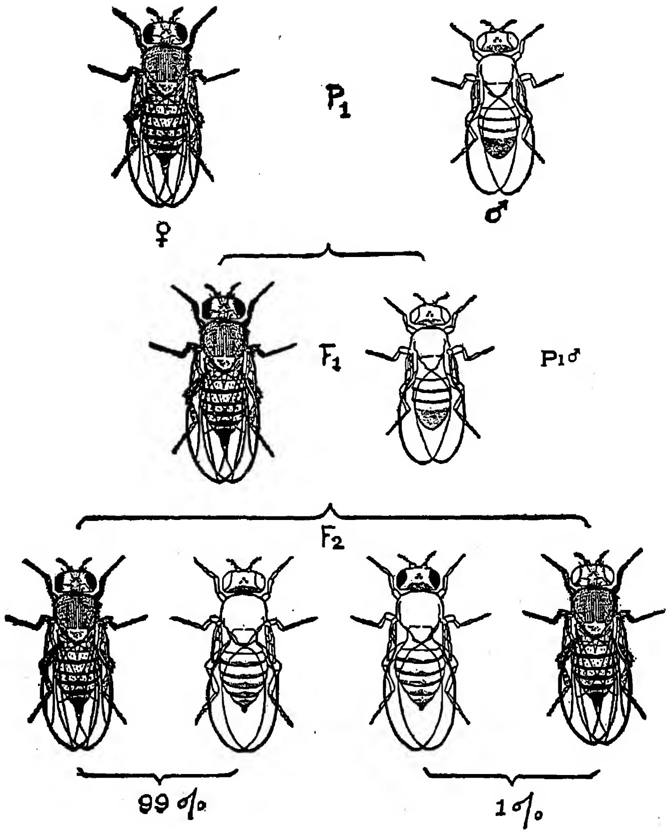


Fig. 79. Crossing-over of Linked Characters

If a male having two recessive mutant characters, white eyes and yellow wings, is mated with a wild female having red eyes and gray wings, the offspring (left in F_1) will all be of the wild type. If such a hybrid is mated to another double recessive, four kinds of offspring will result (F_2), but instead of getting a typical Mendelian segregation, we find that 99% are like the grandparents (dominant for both traits) and only 1% are reversed. That is, there is linkage, but the linkage is not perfect. From Morgan, The Theory of the Gene, published by Yale University Press.

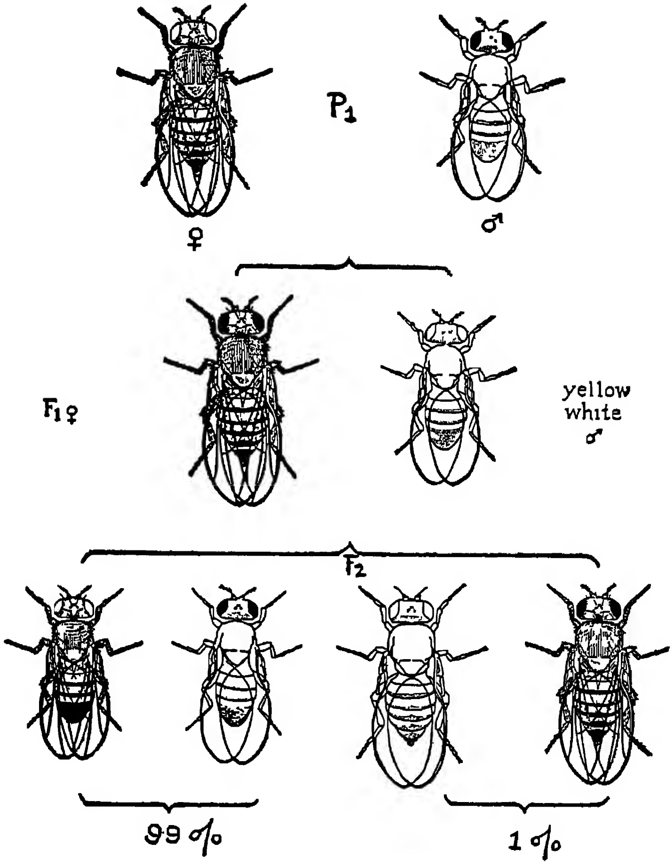


FIG. 80. CROSSING-OVER SHOWN IN A RECIPROCAL CROSS

If a female with white eyes and gray wings is crossed with a male having red eyes and yellow wings, the offspring will be dominant for both characters, that is, have the wild type appearance (left in F_1) If such a hybrid female is mated with a double recessive male, four kinds of flies will be produced in the F_2 generation Again, in 99% the two characters that went in together come out together, showing linkage, but in 1% the combination is reversed, showing that linkage is not entirely perfect From Morgan, The Theory of the Gene, published by Yale University Press.

Mutations

There has now been established by means of experiments a direct connection between the appearance and behavior of chromosomes on the one hand, and the results of crossing or hybridizing on the other. This has made possible

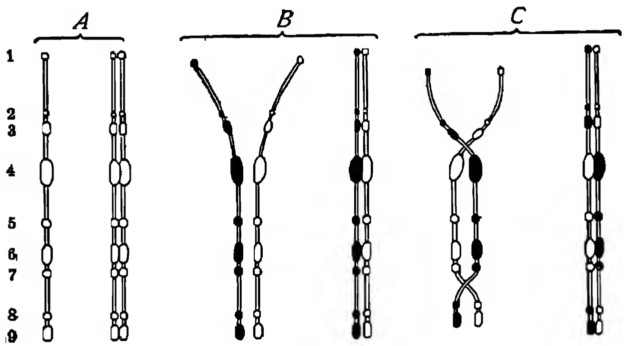
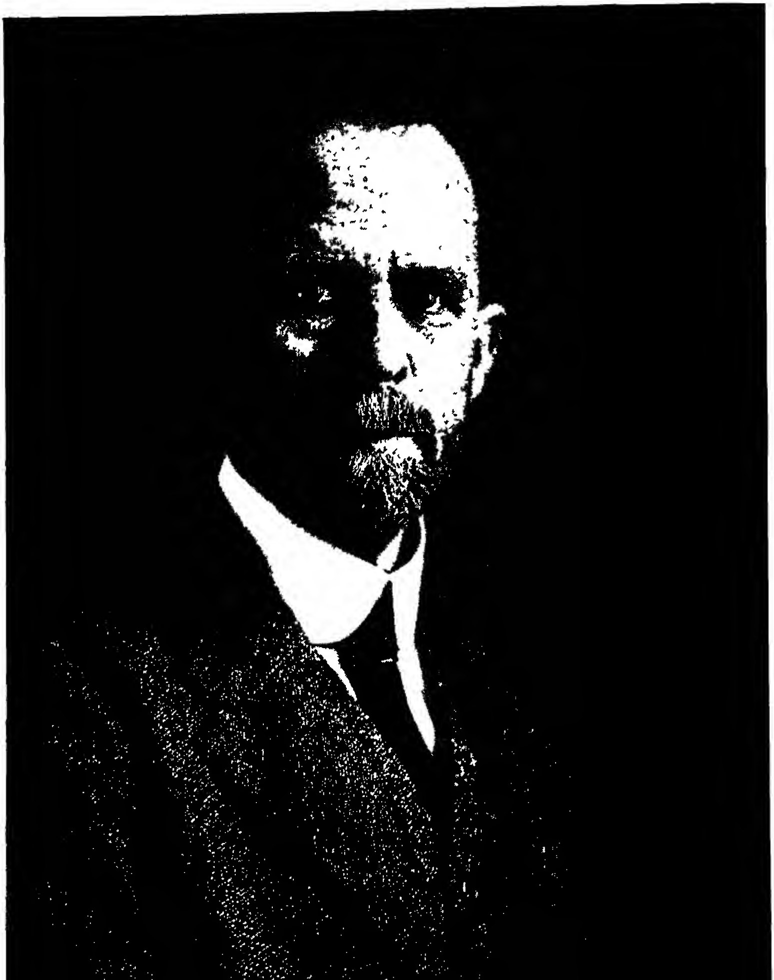


FIG 81. THE IDEA OF CROSSING-OVER

The Mendelian determiners or genes are supposed to be arranged in the chromosome in a linear order, 1–9 in *A* In the formation of a germ cell each chromosome splits lengthwise, so that each new chromosome has the same series of genes, arranged in the same order (*A*) In fertilization the two corresponding chromosomes from the two germ cells (one shown in black, the other in outline) combine so that the genes unite in pairs (*B*) When the two corresponding chromosomes become twisted during conjugation a crossing over may occur so that when the members of a pair are clear of each other (C) each chromosome contains some paternal genes and some maternal ones The breaking of a chromosome with the resulting cross-over of groups of genes is more likely to occur near the middle of a series than near the end On the other hand, where two breaks occur (as suggested in the diagram), they are more likely to take place between the middle point and the ends From Wilson, The Cell in Inheritance and Development, published by The Macmillan Company.

a clearer understanding of how new forms arise. The experiments initiated by Mendel, and forgotten for a generation, were resumed in different parts of the world at the beginning of this century and carried on very intensively with many different species of plants and animals. In every extensive study there have appeared from time to time individuals having one or more distinct characters differ-



Thomas Hunt Morgan

United States of America 1866

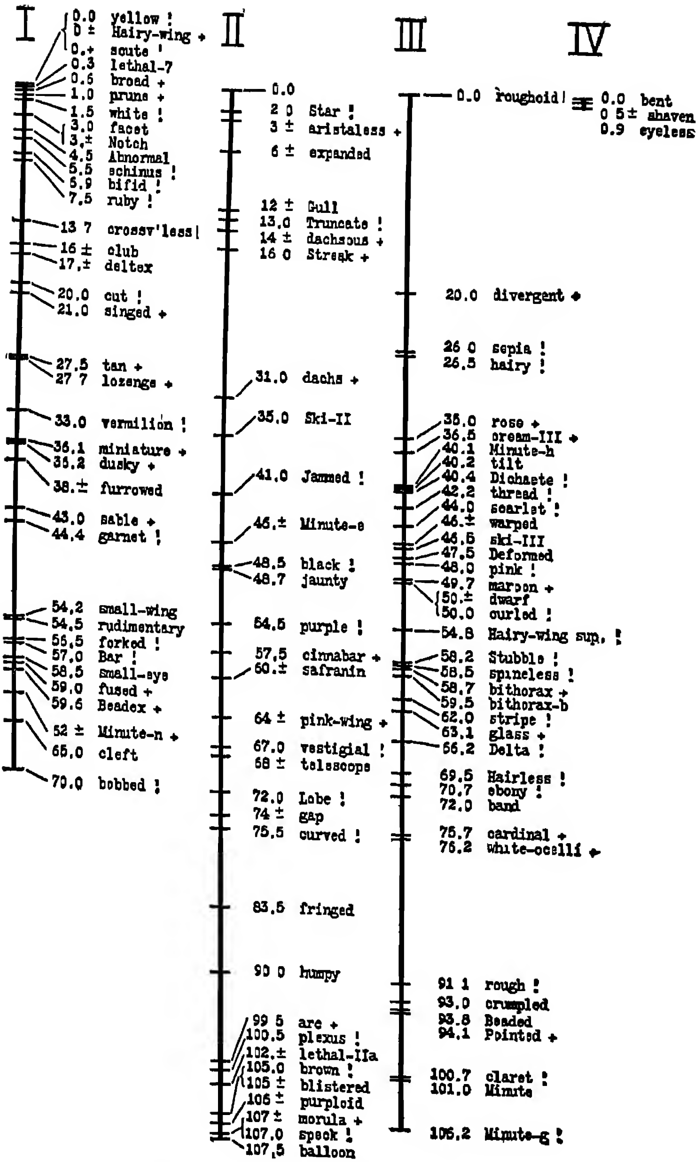


FIG. 82 THE CHROMOSOME MAP OF THE FRUIT FLY

By a study of linkages and the breaking up of linkages Morgan and his associates found four groups of characters that correspond to the four pairs of chromosomes, they found the probable order on each chromosome in which the corresponding genes occur, and they found the relative distances of these genes from one another for over a hundred mutant traits. From Morgan, The Theory of the Gene, published by Yale University Press.

entiating them from the parental type. These "mutations" are found to transmit their distinctive traits either as recessives or dominants, and thus indicate some change in the chromosome mechanism. In addition, therefore, to the many recombinations of traits that hybridization may bring about in accord with Mendel's law of segregation, there appear new traits making possible more new combinations.

Most mutations involve very slight although distinct changes, and therefore do not raise the question of a new "kind." In other cases the entire appearance of a plant or animal is altered, and yet a freak sheep is still sheep enough to be recognized as such and at the same time mutation enough to be considered a freak (see page 182). One significant fact about mutations is that when such a character appears it comes in a single step and not by a succession of small steps. In many cases the mutations appear in one sex and remain sex-linked in succeeding generations. In such cases we would assume that the germinal change takes place in one of the sex chromosomes. In other cases a mutation, although appearing in a single individual in one or the other sex, becomes in a few generations characteristic of the whole stock, that is, of both sexes.

The frequent appearance of sex-linked mutations among the experimental insects has led to a reëxamination of certain well known species, especially butterflies, in which the females differ from the male, and in some of which there are two or more distinct female forms. Darwin had attempted to explain these sex differences as due to the result of sexual selection, assuming that the males preferred, in the female, one type of pattern to the other, with the result that in the course of generations the preferred type came to prevail. In other species the appearance of the distinct patterns was explained as having a protective value to the species, since some patterns resembled forms that were not destroyed by the enemies (birds, lizards) to the same extent (see page 346 and Fig. 88). Breeding experiments among the insects showing these many forms would indicate

that the patterns result from combinations of factors inherited in Mendelian fashion. Incidentally, field studies have rendered extremely improbable the notion that the patterns have any great significance in giving the species a protective advantage.

Experiments have also been extended to wild animals and plants so that we may say with certainty that mutations presenting heritable traits appear in all species, and that the Mendelian formula of inheritance is a universal phenomenon.

Genetics and Evolution

The experimental study of heredity, which Mendel considered essential to a clear understanding of the historical process of evolution, has failed to reveal a single instance of the transformation of one familiar species into another. It has revealed, however, first of all the need for modifying our traditional conception of species. We see from these experiments that the species itself is a composite of several to very many hereditary strains. We see that the species is subject to change in two ways. (1) The constituent hereditary factors may recombine in numberless ways. (2) New hereditary capacities appear from time to time and show themselves in more or less extensive modification of the specific type.

There have been described distinct species — " good " species from the classifier's point of view — which turned out upon examination to be mutants from other strains. If the origin of such mutants had not been observed under controlled conditions, we should not have suspected that *one species does actually give rise to another by a sudden jump*. Genetic analysis (that is, experiments in hybridizing and segregation) has enabled us to distinguish the sudden appearance of such a new strain from the recombination of characters through hybridization. Dozens of such new species have arisen and they behave in every respect as do natural species. Experiments in which distinct natural spe-

cies have been hybridized are comparatively few, because in many cases we find the chromosome mechanism of the two lines incompatible at one or more points. Such incompatibilities account for the frequent interspecific sterility, which used to be considered the essential test of species. The incompatibilities arise also, however, in the course of the experimental study of known mutations from a common ancestry.

The appearance of a mutation in a given direction does not of itself increase the probability that further change will continue in the same direction. In so far, however, as a mutant continues to live and to reproduce itself, its constitution and its capacity for producing new mutations will be a factor in further change.

The facts of mutation so far observed and the facts of heredity determined experimentally give us unmistakable assurance that the transmutation of species is in accord with the nature of living things. These facts also give us a clue to the mechanism whereby living strains maintain their stability on the one hand, and adjust themselves, on the other hand, to changing conditions in the course of ages.

THEORIES OF EVOLUTION

Chapter 9

Theories of Evolution and Creation

MAN'S experience upon the earth places before him constantly a great variety of practical problems. The solution of these must in many cases be found immediately in the form of suitable action. Failure to act suitably means privation, suffering, or even death. In this respect the human organism in a hypothetical "state of nature" is exactly like other living things. But man as we know him is tempted by his experience to formulate for himself problems that do not demand immediate solution and that permit the unrestrained play of the imagination.

In addition to all his other traits, man is a speculative mind. Among the earliest records of his thinking are evidences of his speculative attempts to solve the problems which Darwin summarized in his epoch-making book, *The Origin of Species*. Man has asked not only regarding himself, and regarding the things about him, Whence? and Whither? The history of thought shows three rather clearly defined steps. Every set of important problems has been approached at first through vague wonder and speculation. With the accumulation of knowledge, especially on problems dealing with concrete matters, there comes a time when resort to observable facts characterizes the search for answers. Observation and inference constitute the beginnings of science. Eventually, the systematic pursuit of knowledge leads to the method of experimentation. The progress from speculation to experiment is always slow, but has proceeded much more rapidly in some lines of thought than in others. The problem presented by organic structures and processes has arrived only recently at the third stage.

Speculation, untrammeled by too much knowledge, invents explanations of what happens. These explanations are in terms of such mastery of the environment as is already attained. Like the creative imagination of the poet or artist, speculation can transcend experience. It can do this, however, only in the sense that it can break asunder what we find to hand and recombine the elements of experience into forms not found in nature. Goblins and fairies, invisible forces — more or less disguised homunculi — are improvised to account for all natural phenomena. With the growth of knowledge the speculative constructions are qualified. Poor guesses are supplanted by better ones, and the better ones are remodeled and brought down to date.

The Rise of Objectivity

The conscious substitution of observation and reason for authority and faith as a guide to the realities of the world is a comparatively recent experience for civilized man. Sporadic outreachings toward this mental level appeared in all ages, but a more or less continuous movement toward such substitution may be dated roughly as from the middle of the Sixteenth Century. An epoch is marked by the Copernican doctrine that the earth is not, after all, the center of things. The thought that the earth is a relatively small speck among several others revolving about the sun, which in turn is one of many stars, was revolutionary. It upset people's ways of looking at the world and of thinking about it. It was not at all an academic matter, since it affected fundamental attitudes toward life and death, toward church and state, toward God and destiny.

However foolish you and I today may consider the confusion of religion with dogmas regarding the nature of the physical universe, the trial of Galilei for heresy (1633, less than three hundred years ago!) was directed by sincere concern for the spiritual welfare and salvation of the human race. It does not help, at any rate, to assume that persecution for

heresy, or fear and hatred of new ideas, must indicate stupidity or malice. Consider for a moment that when Newton promulgated his law of gravity no less an intellect than Leibnitz raised objections on the ground, first, that the law of gravity is nonsense since Newton himself did not pretend to know just what gravity is; and second, that the law is wicked since it is opposed to natural religion.

The Copernican dislocation of the earth from its accustomed place in the center of the universe shook men up. They began to resort to facts as possible aids in the solution of the general question. Roughly speaking, this period of observation and inference extended from the last quarter of the Eighteenth Century to the end of the Nineteenth Century. Those who looked at nature for facts rather than symbols never doubted that the transformation of species does actually go on. They were looking for facts to explain *how* species came to be transformed.

Eighteenth Century Evolution

Georges Louis Buffon, who was director of the Royal Gardens in Paris from 1739 to the time of his death in 1788, was a very popular writer on natural history subjects. On account of his official position he was obliged to be very circumspect in expressing views that might displease those in authority. Besides, he liked himself too well to arouse hostility. He did, however, note in his voluminous writings many observations on the direct influence of climate and other factors of the environment in modifying the structure of plants and animals. He made many observations on the adaptations of living things. He repeatedly intimated that new varieties of organisms were formed both through human interference and through the natural processes seen to act upon the individual. Buffon's veiled theories did not present a consistent philosophy of evolution. Many of his guesses as to how adaptations are brought about and as to how new types of organisms originate are not today

considered valid. Buffon did nevertheless attempt to go beyond the general theory of transformation by searching for explanations in the actual, observable plants and animals.

Toward the very end of the Eighteenth Century, Goethe in Germany, Geoffroy Saint-Hilaire in France, and Erasmus Darwin (the grandfather of Charles Darwin) in England made independent attempts to formulate an explanation of *how* change in organic forms is brought about. Each of these thinkers was impressed by the outstanding characteristic which living things have in common. These are a more or less adequate fitness for their respective environments, and, from the point of view of the individual's life, an adjustability to changes in the environment. Each of these writers accumulated numerous concrete facts illustrating the modifications resulting from one or another factor in the environment. And each laid more or less emphasis upon the discriminating effect of the environment, in the sense of exterminating the relatively less well adapted. Not one of these, however, pursued the subject over a sufficiently wide range of living things to bring him to a consistent theory in the modern sense.

We may infer the importance which Goethe attached to the studies from the fact that at eighty-one years he was greatly agitated by the report of a debate on evolution between Cuvier and Saint-Hilaire, whereas he dismissed the news of a political revolution, received on the same day, with indifference. The debate between Cuvier and Saint-Hilaire was formally won by the former, who in addition to being a master of comparative anatomy, had a more ardent disposition than the meditative Saint-Hilaire. All the intellectual centers of Europe were stirred by this debate. It turned the attention of the younger scientists and scholars to the issue, but it also had the effect of obstructing a serious consideration of ideas favorable to evolution. Cuvier, like Linnæus, assumed the fixity of species. Lamarck and Saint-Hilaire, on the other hand, had concerned themselves with

finding in the facts of nature an explanation of how things came to be as they are. Because of the absence of detailed observations, the idea of the transmutation of species was at the best a plausible inference; or it was a foregone conclusion on philosophical grounds.

Cataclysms with Supplementary Creations

During the first quarter of the Nineteenth Century there was no man living who was better informed than Cuvier regarding the structure of various types of animals, both living and dead. No one was better informed regarding the actual succession of animals in past ages. Cuvier saw clearly enough that the earth had been inhabited in past times by forms that no longer existed. From the fossil remains of crocodiles and elephants, of hippopotamuses, and rhinoceroses, and of other reptiles and mammals that abounded in the jungles and swamps which at one time occupied the region that is now Paris, Cuvier read the story with remarkable precision. To him it was perfectly clear that there had been through the ages "an upward development in the animal forms inhabiting the globe."

But this did not mean to Cuvier the steady transmutation of species. What he saw was long periods in which the flora and fauna remained immutable, alternating with relatively brief periods of violent and unthinkable cataclysms that swept everything away. After each cataclysm a new creation repeopled the earth with higher forms of plants and animals, modeled, however, on the traditional types. In this way, thought Cuvier, it came about that the living beings of our time are different from those of the past. In this way it came about that successive ages presented more developed forms. The theory of periodic cataclysms, of which the Biblical flood was the latest, though probably not the last, was satisfactory on philosophical grounds. For it did not inquire too curiously into the mechanisms or the

evidences of the cataclysms, nor into the mechanism of the successive creations. At one time Cuvier surmised that these cataclysms might perhaps not have been universal in extent. The repopulation of an area might then result from migrations out of unaffected regions. This thought, however, he could not maintain consistently for there still remained to explain his own doctrine of progressive succession of higher and higher forms.

Uniformitarianism

During the year in which Cuvier debated before the Academy of Sciences with Saint-Hilaire (1830) there appeared in England an important book by Charles Lyell, *The Principles of Geology.* Lyell took his cue from James Hutton, a Scotchman of the Eighteenth Century, who approached the problems of geology with a rather fresh mind. He insisted, in effect, that the structures and formations of the earth's crust be interpreted in terms of *known forces operating in our own times in known ways.* In other words, we should treat the problems of geology as nearly as possible as matters of fact and not by means of unfounded speculations. Lyell applied Hutton's thought by actually studying the processes by which rocks are weathered, soils are eroded, silts are deposited, gulleys are cut by rivers, dead animals are buried by mud, and so on. This was a projection from the known to the unknown. It took in this case the inevitable form of assuming that the forces today at work in making and remaking the crust of the earth were at work yesterday and all through the past. It meant that the known forces were sufficient to account for the facts as presented by the crust of the earth and its inclusions. It meant that there was no need to assume other types of agencies to explain what has happened in the past.

These principles were based upon a study not only of the earth in its static phases, so to say, but also of the dynamic events that are in our own time reshaping the earth.

They were elaborated into the doctrine of uniformitarianism, and in the minds of scientists they shattered the cataclysms of Cuvier. With all due allowances for errors in details of observation and inference, the doctrine of uniformitarianism remains after all the only sound principle for any attempt at understanding the world scientifically. It means, in effect, that in our efforts to interpret the facts of nature we must rely upon what we know positively. Where known agencies and forces can be made to serve, we must avoid improvising agencies and forces to explain events. It is of course impossible to " know " that processes which are going on before our eyes were going on before our days, or will continue to go on after we stop watching. It seems, nevertheless, much more reasonable to assume continuity of essential characteristics of the materials and forces of the world than to resort to the interposition of mysterious agencies of whose nature we know nothing.

Theories and Guesses

Although it is true that we can never have any direct knowledge about the historical past, it does not follow that one surmise is as good as another. We have unfortunately suffered incalculably in the course of our cultural growth from the vulgar assumption that in the absence of direct knowledge we have either to accept the teachings of inspired authority or remain free to make up our own guesses. The scientist formulates theories and hypotheses which, from the nature of the case, cannot be immediately or directly demonstrated as " true." But these theories are not free or irresponsible guesses. They are reasoned constructions that are controlled by previous experience and knowledge, and that are subjected to further control through logical criticism and careful checking against the facts of observation and experiment. It is as futile and puerile as it is unfair to identify such mental products with guesses and opinions.

The First Scientific Theory

Lamarck stands out as having attacked the problem of evolution by appealing to a wide range of facts, and as having embodied his interpretation of the process into the first complete theory of descent. The influence of Cuvier, who bitterly opposed Lamarck, largely prevented a wider consideration of the fundamental issue. The merits of Lamarck's special theory we shall consider presently. The importance of his writings consisted not so much in the validity of his explanation as in his having made the process of plant and animal evolution through the action of natural forces intelligible to unprejudiced persons. Most of those who by disposition or training had accepted the general theory of transformation of species were not moved to search for the specific actions and reactions of living things and of the environment. As in our acceptance of gravity or electricity we are content to use the ideas or the facts without insisting upon a fundamental understanding.

For half a century Lamarck's work was known only to a comparatively few scholars, praised and admired by some who overestimated the validity of his theory, ridiculed and disdained by others who failed to see the significance of his achievement.

During the first half of the Nineteenth Century there were being accumulated under the influence of the anti-evolutionist Cuvier, of the anti-evolutionist von Baer, of the skeptical geologist Charles Lyell, and of the anti-evolutionist Agassiz, vast numbers of direct observations in anatomy, in embryology, in geology, in morphology and in paleontology. There were accumulated also records of horticulturists and animal breeders, the observations of travelers and fanciers, and minute descriptions of plant and animal forms by students of classification. By the middle of the century this large mass of facts finally made it possible for Charles Darwin to formulate the process of organic transformation in terms that appealed to the common sense of

all who were acquainted with the facts. The instant success of Darwin's theory among scientists reopened the older issues upon which Saint-Hilaire and Cuvier had debated, namely, whether species were fixed from the time of creation or whether transmutation does in fact take place. In the heat of controversy it naturally came about that the general question was confused with the special theory, and the disentanglement of the two is far from complete even among scholars and educated laymen.

From Observation to Experimentation

The rise of Darwinism as a plausible explanation of transformation stimulated research in every direction, much of it deliberately designed to support or illustrate the doctrine of natural selection. An increased amount, however, was deliberately planned to find more and more fundamental facts.

As we all know, the physical sciences were making rapid progress during this period through the elaboration of experimental methods of research. Gradually the biologists took over more and more of the experimental method. By the end of the Nineteenth Century it was possible to attack by means of experiment the many special questions raised by the discussion of evolution and natural selection.

This is not to say that experiments had not been conducted before 1900, but only that at the present time experimentation is found to be feasible in the biological sciences and is generally accepted as furnishing the ultimate tests for any theory. As we have already seen, the Catholic priest, Gregor Mendel, selected the problem of heredity as the crucial one in the evolution of organic forms, which, like his patron saint, he accepted as a matter of course; and he devised experimental methods for clarifying this process. This experimental attack did not influence the course of study and discussion since the results were shelved in the

reports of a local natural history society. Essentially the same discoveries, however, by essentially the same methods, were subsequently made by at least three individual investigators experimenting with many different types of plants and animals — de Vries in Holland, Correns in Germany, and Tschermak in Austria. Curiously enough, these independent investigators, who in searching the literature of the subject also discovered the earlier work of Mendel, announced their findings almost simultaneously at the end of the Nineteenth Century.

Sources of Opposition

It is not at all surprising that the doctrine of evolution has met with frantic opposition and violent denunciation from many sources. Even among the professional scientists of fifty years ago the Darwinian proposal was often received with condemnation on the ground that it upset things too much. At one of the annual meetings of the German association of scientists and physicians *The Origin of Species* was debated by Rudolf Virchow, the founder of scientific pathology, and Ernst Haeckel, the protagonist of the "recapitulation theory." Virchow did not feel the necessity of dissecting Darwin's theories on their merits. It is indeed doubtful whether there were at that time a score of men in the whole world sufficiently conversant with the essential *facts* to discuss Darwinism critically. Virchow at any rate considered that he had adequately disposed of the new heresy by warning the world that the adoption of these pernicious teachings would lead straight to socialism! The young Haeckel, on his part, full of enthusiasm for the new gospel, resorted to precisely the same methods. The best he could say in support of Darwinism was a logical demonstration of the thesis that unless we all adopt this view of the world and of life, nothing can save us from socialism! Again we see an attempt to approach a problem scientifically — that is, through the rational treatment of ascertained facts —

obstructed with fears and alarms from those who feel their security threatened.

This method is not confined to ignorant men and women who apply literally in their adult years what they learned in childhood as poetry. Quite recently an eminent scholar and religious leader seeks to demonstrate the untruth and menace of evolutionism by citing, among others, (1) the spread of Marxian socialism under the inspiration of materialistic evolution, with dire consequences (*a*) in the suicide of Marx's daughter and (*b*) in the Russian reign of terror; (2) the infection of modern society with the virus of animalism, egoism and perfidy; and (3) the startling murder of a boy by two young college men who "had been taught by their professors that scientific psychology dispenses with the soul, and that the differences between men and brutes is one of degree only, and not of kind." Clearly, any doctrine that will bring to the world so much sin and suffering must be barred out, regardless of its attractiveness to its sponsors and partizans!

The General Theory of Evolution

As a working hypothesis with a high degree of probability, the general idea that there had been modification of plant and animal forms is acceptable to all who have taken the pains to acquaint themselves with the pertinent facts. It is the only view we have today that is in harmony with the established facts. As a working hypothesis it serves as a very satisfactory guide to the organization and extension of research in many directions, and as a very effective means of unifying facts of observation and experiment, for convenience in handling them, and for practical application. Although evolution, in the sense of transmutation of living forms, rests upon facts and logic, it remains, for most of us, merely a highly probable hypothesis, since it is impossible to take the skeptic to a high mountain or into the backyard and show him one species being transformed into another.

The general theory of the transformation of species has nevertheless passed beyond a philosophical speculation and is accepted by practically all biologists and paleontologists as a historical fact. The agreement namely is upon the proposition that *species have changed in the past and do change today.*

Spontaneous Generation

Objection has been made to the general doctrine of evolution that by avoiding the question of the origin of life it admits the doctrine of spontaneous generation. This is perfectly true. Curiously enough, however, while the spontaneous generation of living matter in the ordinary understanding of this expression is rejected by the scientists, it is quite commonly believed by large numbers of people, including a large proportion of those who oppose evolution. And was directly accepted by Cuvier himself!

Even those, however, who accept the general theory of organic evolution as a historical fact are not agreed on the validity of any of the special theories which attempt to explain the causes of change.

Confusion of General and Special Theories

There has accordingly appeared a type of criticism of the general evolution theory which hardly deserves serious consideration except that it is frequently employed to the discomfiture of reasonably intelligent people when the latter are off their guard. This is the device of setting up criticisms uttered by various scientists upon the theories of others, gently leading on to the conclusion that all the quoted scientists repudiate evolution. It is essentially a confusion between the general doctrine of transformation with some specific theory to explain the process. The failure of any or all of the latter is made to "prove" the untenability of the former. The argument may be formulated something like this: "The ways of evolution pass all understanding.

We can make only theoretical and fragmentary attempts to explain what happens. Therefore, there is no evolution — that is, nothing happens." We may paraphrase the logic of this argument into a more obvious absurdity: "The ways of God pass all understanding; the fool sayeth therefore in his heart, there is no God."

A complete theory has placed upon it a very heavy burden. There have been developed numerous special theories although not one of them is satisfactory in every respect.

What a Special Theory Must Do

Any theory that attempts to explain *how* evolution goes on must in the first place be in harmony with common sense, that is, with the established principles regarding the action of known forces upon known materials, and more particularly the principles regarding the action of organic matter. Thus, a complete theory must answer the significant questions regarding heredity and must harmonize with the known facts of reproductive processes, of the germinal mechanism, and of individual development. It must answer the question of the sources of variation, particularly of the kinds of variation that are transmissible. It must answer the question of organic response which we take to be the foundation of individual adjustment, and of species adaptation, if this is indeed a distinct order of fact.

Moreover, a complete theory of organic evolution must point to processes that are observable today, even though it may not present to us the actual transformation of species during the period of observation. That is to say, it must harmonize with the assumption of uniformity in natural processes. A complete theory must be adequate to account for changes recorded of the past, as well as for the existence of living forms. And finally, it must explain the origin of adaptations as well as the mere transformation.

We demand of a scientific theory today that it enable us to predict to some extent future findings and develop-

ments, as well as to explain what has already happened For example, a complete theory of evolution ought to be applicable to the breeding of plants and animals; to the restoration of a living population to a desert or denuded area; to the restoration of the balance of nature brought about by the introduction of new species into a given area or by the elimination of existing species; and to the many problems of human migration and social control of differential birth rates — the problems of eugenics or race improvement.

Special Evolution Theories

There are several types of theories calculated to explain how the world of plants and animals came to be what it is, what makes it constantly change. Some theories attempt merely to interpret certain kinds of facts in terms of natural processes, uniform results of uniform causal forces. Others attempt to be more comprehensive and to explain all of the principles. There are three major facts to be accounted for: the fact that living things are adapted; the fact that there is variation; and the fact of heredity.

Adaptation has been attributed to the essential nature of protoplasm or living matter, an ultimate fact like mass or extension. That is to say, it has been accepted *as given* without any attempt at further explanation or analysis. It has also been attributed to an inner striving or effort, which is hardly to be distinguished from the first. Lamarck assumed the presence of this innate principle in the first living things created, and explained the further development of mechanisms and functions during the evolution of plants and animals as the result of the inheritance of the gains due to the exercise of this primary adjustability. Darwin accounted for adaptation by assuming fortuitous variation as a universal fact of living matter, and the selective effect of natural conditions as the means of eliminating the relatively less fit. Natural selection or survival of the fittest accounts

for both the progressive appearance of new forms and the constant fact of the fitness of life to the existing conditions. An innate principle making for perfection has also been suggested, but in the minds of most people this approaches too close to mysticism to be of value as an element in a scientific theory.

If there is to be transmutation of species, there must be variation. Variation had been observed from early times, and has been taken for granted as the raw material of evolution by many thinkers. Darwin, in developing the principle of natural selection, realized the importance of variation but did not make it his business to find out how variations come about. Nor did he distinguish clearly and consistently between variations that fluctuate with changing conditions and those that are transmitted. Lamarck attributed certain kinds of variations to the direct action of the environment upon the individual, and others to the inner action in response to external stimulation. He assumed also that variations of the latter kind are transmitted to the offspring. It was only after the study of heredity had made considerable advance that the distinction between inherited and noninherited variations came to be emphasized as important, in the theory of evolution. By the end of the Nineteenth Century scientists were prepared to consider as a basis of evolution the appearance of saltations or jumps — individuals that depart in a definite way from the parental type and transmit their distinctive characters to their offspring. The more intensive study of the mechanism of heredity has given rise to theories about the origin of heritable variations through some process which affects directly the germinal substance or the chromosomal material.

Until our own time there were no thoroughgoing theories of heredity that could help clarify the facts of transmutation. Everybody knew that like begets like, but there were not enough facts at hand to suggest even a remote approach to the mechanism. Francis Galton, a cousin of Charles Darwin, had gathered a large mass of material for

statistical study, from which he had learned to state more precisely what everybody already knew — individuals resemble their parents more than they do their uncles and aunts; and that they resemble their brothers and sisters more than they do their parents. Remoter ancestors " influence " heredity in some way, and a mathematical formula could be developed to measure degrees of resemblances or differences.

Useful theories regarding the mechanism of inheritance had to await a more thorough knowledge of cells and cell formation, especially the behavior of the cell nucleus, and more definite information regarding the precise manner in which particular characters reproduce themselves. With Mendel's experiments, with Weismann's theory of the germ plasm, and with the work of many cytologists on the cell processes, a scientific theory of heredity began to take shape at the beginning of the present century. This theory assumes a more or less stable germinal material that continues to carry the potentialities of the individual and of the race. This is supposed to be uninfluenced directly by the exigencies of the individual's life and development, but nevertheless subject to change in detail so as to give rise to individuals that differ from their parents in heritable traits. The theory of the gene, as developed by Thomas H. Morgan, accords with the facts at present known and supplies a theoretical explanation of the stability of species as well as of the appearance of new forms.

Creation and Evolution

The supposed incompatibility between evolution and religion (or rather theology) is a comparatively modern affliction. We have already noted that Saint Augustine and the Catholic theologians generally were consistent evolutionists in a very modern sense. The recent controversies have had to do not so much with the scientific theory of evolution as with philosophical conflicts which involve funda-

mental questions about the nature of God, about the nature of the world, and about the nature of man.

It is necessary first of all to differentiate both various kinds of evolution theory and various kinds of creation theory. It may be admitted at once that " creation " as an explanation of the world is the most complete that anyone can ask for, and at the same time the least satisfactory for anyone to whom the question *How?* has any real meaning. The church fathers who had come in contact with pagan philosophers were stimulated and influenced by them. Saint Augustine and others were particularly sensitive about appearing foolish and ignorant in the presence of these scholars. In harmony with the prevailing thought of the time they looked upon the historical process as an evolutionary one. God in his act of creation gave to matter those qualities which we today consider inorganic and also those others which made possible for it to become highly organized, and eventually living matter, through the operation of natural forces — that is, in accordance with observable uniformities of action. This doctrine is today acceptable to many devout Catholics in good standing, including leaders in the church.

In the effort to avoid the idea of transformation and at the same time accept the facts, various curiosities of reasoning have been put forth. One interpretation of Saint Augustine's position, for example, grants that the churchman conceived creation to have established a material world in which living things would evolve out of non-living matter, but does not grant that this includes the evolution of species. This view means, in effect, that each type of living thing may have arisen originally from non-living matter — through spontaneous generation — by virtue of the properties with which non-living matter was endowed by the act of creation, but that each species has remained constant ever since. The only issue between the scientist and the creationist is here one of fact: Has there been transformation of species?

Canon Henri de Dorlodot, at Louvain, thus explains how scientific evolutionism may be harmonized with the doctrine of creation. He writes:

> "1. The primary origin of living beings is the result of a special influence on the part of the Creator, Who infuses life into one or a few elementary organisms.
>
> "2. These organisms, by evolving in the course of ages, have given rise to all the organic species which exist at the present time, as well as these which have come down to us in the fossil state"

These views of the general fact of organic evolution are in every essential identical with those of the modern scientist. Indeed it has become quite fashionable for scientists to repeat the formula, "Religion tells us about creation; science tells us how creation was accomplished." Of course religion does nothing of the kind: it attempts to find for man a way of life that will yield an optimum of spiritual values. And of course science does not tell us how creation was accomplished: it tells us only what it can infer from the present facts as to probable events of the past. At any rate, the only conflict between creationism and evolutionism that does not confuse a thousand irrelevancies arises at one or another of two points:

(1) The scientist may go out of his way to deal with philosophical questions of origins and come into conflict with a special theological theory of origins. Or,

(2) the theologian may insist that the scientist accept his version of creation, as an ultimate fact or as a basis for interpretation.

Creator versus Evolution

We may thus see that the evolutionary point of view has been acceptable to theologians who think definitely in terms of a personal God and an act of creation. The theologian is free to postulate creations according to a great variety of plans. The scientist is compelled to accept the

world as he finds it, to study its workings, to make his generalizations, to test his views without going back to first beginnings.

The only doctrine of creation which comes directly into conflict with the general theory of descent is that formulated by Suarez among the theologians, and by Linnæus among the naturalists. This is the doctrine that all living beings were created in specific forms once and for all and have remained fixed through all the generations of descent. While the scientist does not presume to say anything about the first creations, he does say with a great deal of assurance that species today are different from the inhabitants of the past; that many living forms of bygone days are completely extinct; and that there are living plants and animals today of a kind that did not exist in ages past. He asserts that these changes have come about through the action of natural forces of a kind to be seen at work today. He does not feel the need of postulating successive acts of creation to account for either the species that have become extinct or for the species that have made their appearance within the time recorded by the earth itself.

Evolution not Irreligious

Evolution is compatible with religion. This is not to say, however, that the *facts* upon which the evolutionist relies or the *theories* through which he explains observed happenings can be reconciled with all the specific theologies and superstitions and rituals that have been accepted as part and parcel of "religion." We can mean no more than this: the emotional and sentimental factors of human nature which go to the making of hope and aspiration, of devotion and sacrifice, of wonder and worship, of humility and reverence, of confidence and fortitude, and so on, are accepted by the evolutionist as present, without prejudice either as to how they have come to be or as to what use is made of them by different peoples at different times. The evolutionist as

such does not feel called upon to affirm or to deny the truth, beauty or worth of any system of religion whether it be Confucianism or Congregationalism, Buddhism or Baptism, orthodox Judaism or liberal Unitarianism. As a scientist, he is concerned with checking alleged facts, with testing hypotheses, with modifying hypotheses and theories into harmony with new facts, with formulating new hypotheses that lend themselves to experimental or other verification — or refutation.

Evolution as a way of thinking has undoubtedly modified the God-concept for millions of people. But precisely the same may be said of the teachings of every religion, of every missionary. We excuse the latter on the ground that missionaries help people advance from a primitive or childish conception of the deity to a more exalted one. We must allow exactly the same credit to any agency that brings similar modifications. It may well be that some individuals have become completely demoralized through their conversions — both through the changes brought about by the teaching of evolution and through the changes brought about by the teaching of religious gospels. But even as the missionary justifies himself by the greater good he has brought to thousands who accept his way of salvation, the scientist would point to the spiritual gains of vast numbers who have been liberated from fear and superstition by scientific teaching.

There is still widely prevalent the conception of a supreme power as a person who manifests his superiority by interfering from time to time with the orderly processes of nature, whether to show his pleasure or anger, whether to please those whom he likes or to penalize others who have not paid him a full measure of homage — a supreme power in other words, who behaves on occasions like a rather immature human being. In so far as scientific knowledge has influenced theological speculation, it has served to make the deity less concrete, less personal, less constrained by the pettiness and jealousies and crudities of ordinary human beings. Science has done this by extending the borders of God's uni-

verse, by expanding the range of his activities, by magnifying the force of his influence The result has indeed made it more difficult for the individual to deal with the deity in the intimate manner of one seeking special favors or bargaining for advantages or compromising on obligations. The argument, however, that evolution *therefore* interferes with the moral life is on a par with the arguments that one system of religion has in the past hurled at each of the others, on a par, for example, with the doctrine that heretics are wicked, or that Catholics do not have to be " moral " because they can go to confession periodically and wipe their record clean.

Evolution not Religious

It is futile, on the other hand, to claim any specific religious value for the scientific doctrine that species have become transformed. To say, for example, that " the ethical principle inherent in evolution is that only the best have the right to survive," or to say that evolution reveals God " through the countless ages developing the earth as an abode for man " is to reveal a sad confusion of categories. The scientist as an individual may of course find in the facts of nature whatever his religious disposition leads him to. And he may of course bring into his conception of the universe all of his findings and all of his feelings to make a pattern that satisfies his longing for unity. It is a different matter, however, to say that " science teaches " God's purpose or goodness, or anything else that cannot be directly inferred from verified facts. Men and women of all faiths have found the study of science compatible with their morals and with their faiths. This, however, is not primarily the concern of the scientist as such. It is his first business to make sure of the facts. If any find these facts offensive to their sentiments or to their faith, so much the worse for them. It is not the business of the scientist either to promote or to attack faith. As a well known anthropologist has said, " We

do not seek to undermine your faith; but we will teach what our eyes have seen, whether it undermines your faith or not."

It ill becomes scientists who have for centuries suffered through the opposition and hostility of dogmatism to set up any of their own conceptions and interpretations as orthodox dogmas of science — evolution, for example, as a dogma. By the same token, however, they must be on their guard against subordinating research and analysis to a dogma imposed from without — for example, the dogma that acceptability to one or another church is the ultimate test of a scientific idea.

It has indeed been pointed out that, with the recent attacks upon the teaching of evolution in tax-supported schools, many scientists have been stampeded by the attempts of certain obscurantists to identify with the evolutionary doctrine all the failings and shortcomings in contemporary civilization. It is a mistake to charge against the evolutionist the possible misuse to which other people might put his facts and theories. If a Machiavelli applies chemistry to blow up the peasants of other princes, if a Borgia applies chemistry to the poisoning of an unpleasant neighbor, if a bootlegger applies chemistry to the making of bad substitutes for whiskey, the pursuit of chemistry is not thereby made wicked or the findings of chemistry made thereby false science. The scientist should know in his own heart whether his study of evolution has led to his own spiritual undoing. He should be doubly cautious before subscribing to the doctrine that civilization is threatened because scientific teaching — and specifically, if you will, the teaching of organic evolution — makes young people too critical regarding established beliefs.

Chapter 10

Relation of Use and Disuse to Evolution

ONE of the things that everybody knows and, so far as we can find out from the records, always has known is this: Exercise increases power, whereas the disuse of an organ or an ability leads to atrophy or to loss of skill. We cannot promise anybody that through practice he will surely attain perfection; but everybody knows that only through practice is perfection ever attained. The general fact is one of common observation, and is probably never questioned.

Now it stands to reason that those who improve themselves through the exercise of their powers will by so much be likely to have superior offspring. The inference is indeed so patent that it is seldom questioned; and it has been a part of accepted belief, for the most part tacit, for three thousand years or more. Aristotle included this among his observations upon vital phenomena, and lent the weight of his authority to the corollary that has come to be known as the doctrine of prenatal influence, or "maternal impressions." This also has an ancient and respectable tradition behind it, being assumed by at least one of the Old Testament authors — in connection with a certain transaction that attached an economic advantage for one of the parties to an increased number of striped or spotted sheep (Genesis xxx, xxxi).

One of Ezekiel's proverbs has been commonly interpreted not merely as an embodiment of this belief in the transmission of modifications acquired through experience, but as a biblical endorsement of the idea: "The fathers have tasted of sour grapes, and the children's teeth are set on edge." A similar interpretation is also sometimes made

of the threat, or promise, that the sins of the fathers would be visited upon their descendants for a specified number of generations. So commonplace has the thought been in the past that it was accepted uncritically both by those who were rigidly orthodox with respect to the fixity of species, and by those who assumed an evolutionary process of some kind to account for the existing fauna and flora.

Lamarck

During the year 1809, which saw the birth of Charles Darwin, there appeared the masterpiece of Jean Baptiste Lamarck, the *Philosophie Zoologique*. In this was embodied the widely accepted belief in the inheritance of the effects of use and disuse, as part of what was after all the first attempt to formulate a scientific hypothesis to explain the evolution of living forms.

Lamarck was the youngest of eleven children and suffered from his earliest years the hardships and privations of poverty and lack of opportunity for his exceptional intellectual ability. He was sent to a Jesuit college, much against his will; and abandoned theology when his father died, to take up the study of medicine. From this he shifted, under the influence of Jean Jacques Rousseau, to become a botanist of distinction. After the French Revolution the stigma of monarchism had to be removed from the royal garden and Lamarck worked out the plan for reorganizing the botanical garden and the natural history museum. There seemed to be good political reasons why somebody else should become head of the botanical department, so Lamarck was made professor of invertebrate zoology — a field that was entirely new to him, and for that matter, not very old in the world of thought. So at fifty years of age, when he had attained recognition as an authority in two branches of science, botany and paleontology, he plunged with energy into the task before him, and became shortly the leading authority in a third branch, invertebrate zoology.

In the matter of the origin of plant and animal forms, Lamarck had been an orthodox fixist, following in the footsteps of Linnæus. He found the latter's linear system of classification quite inadequate. After extending it to the utmost limits of its possibilities he discovered the necessity of the branching arrangement of classes and orders to indicate natural groups. When he threw himself into the study of invertebrates he brought order into the chaos of classification, especially in the class "worms"; but in the course of his studies he found himself gradually losing his grip on the permanent "species" — and becoming a transformist. The more he studied the more his conviction grew that the existing plants and animals were not only the descendants of the plants and animals of the past, but that *living forms had in the course of time become transmuted into different forms.*

Saint-Hilaire was sympathetic and encouraging, but not very powerful. Cuvier was hostile and aggressive — and influential. When Lamarck brought his views into the open it meant conflicts and bitterness. But he did not mince matters. He knew that the conclusions to which his studies had brought him meant first of all the heresy of transmutationism: the living species were *not* the direct descendants of identical forms originally created, but forms modified in the course of the ages into very different beings. He knew, in the second place, that his doctrine was to be applied generally. He said quite explicitly, "All species, including man, are descended from other species" And he knew in the third place that he was propounding an explanation of *how* transformation of species had come about.

Lamarck's Laws of Evolution

In his *Philosophie* Lamarck summarized his principles into two laws:

"First Law: In every animal which has not exceeded the limit of its development, a more frequent and continuous use of any organ gradually

strengthens, develops, and enlarges that organ, and gives to it a power proportional to the length of time it has been so used; while the permanent disuse of any organ imperceptibly weakens and deteriorates it, and progressively diminishes its functional capacity, until it finally disappears.

"Second Law: All the acquisitions or losses wrought by nature on individuals, through the influence of the environment in which their race has long been placed, and hence through the influence of the predominant use or permanent disuse of any organ, are preserved by reproduction to the new individuals which arise, provided that the acquired modifications are common to both sexes, or at least to the individuals which produce the young"

In the edition of 1815 he expanded the statement into four propositions:

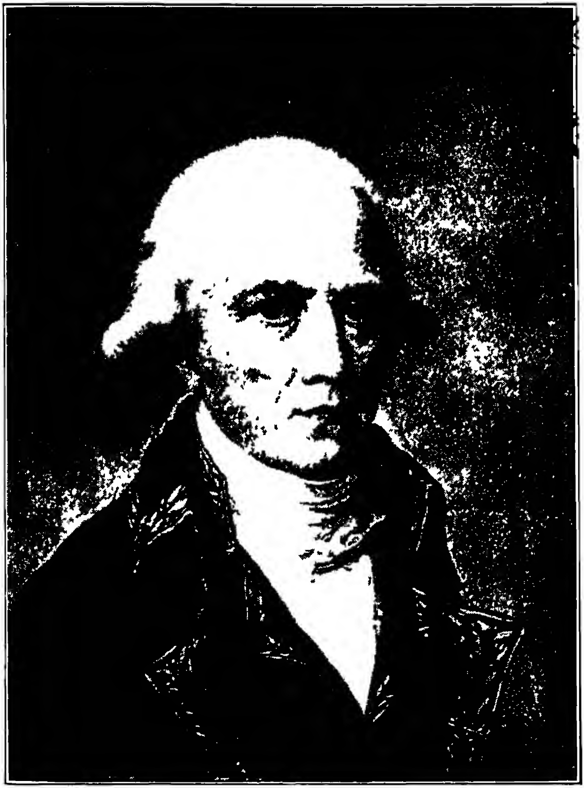
"First Law: Life, through its own forces, continually tends to increase the volume of every body which possesses it, and to increase the size of its parts, up to a certain limit determined by life itself

"Second Law: The production of a new organ in an animal body results from a new need supervening and continuing to make itself felt, and from a new activity which this need arouses and maintains.

"Third Law· The development of organs and their functional capacities are constantly in ratio to the use which they receive.

"Fourth Law: Everything which has been acquired, impressed upon, or changed in the organization of individuals during the course of their life is preserved by generation and transmitted to the offspring of those which have undergone these changes."

Aside from the rejection of the general theory of evolution by Cuvier and others, misunderstanding centered on the second law; and controversy as to the facts assumed in the fourth law has continued to the present moment. For the rest, the meaning is not only unambiguous but quite in accord with common observation and common reason. Lamarck elaborated his theory, however, to include other factors which he took to be of significance in bringing about the modification of species. For example, he drew a distinction between the action of the environment upon plants and lower animals, and its action upon higher animals, those



Jean Baptiste Lamarck

France 1744–1829

having a nervous system and the beginnings of conscious-ness. In the former, vital activity depends upon the stimulation received from without, so that the environment produces direct effects. In the latter, on the contrary, there is the initiation of suitable responses from within, so that the environmental forces act indirectly. Lamarck also noted the importace of the " balance " of nature and what came later to be called the " struggle for existence " and the " survival of the fittest." In discussing the possible evolution of man, he pointed out the bearing of isolation upon the establishment of distinct types, and the danger of an improved form being swamped by the prevailing type.

How Need Modifies the Organism

The second law, which has resulted in a great deal of ridicule and condemnation, is the expression of a philosophical or metaphorical interpretation of the general fact which we observe in living things under the name of responsiveness. Living things either adjust themselves to the conditions of the moment — or they perish. It is hardly fair to attribute to Lamarck, as did Charles Darwin in 1844, the notion that change comes about through " the slow willing of animals." If we make allowance for the difficulty of presenting simply and clearly in 1809 what came in the course of a century to be accessible to schoolboys and schoolgirls, we can the better understand Lamarck's point, whether we agree with him or not. It seems reasonable, in view of his whole work, to consider the doctrine of need or appetency as equivalent to the assumption that the native tendency of an animal is to respond to a change in the environment, or to a stimulus from outside, *in a manner appropriate to its own needs.* How far is this tendency actually present? How effective may it be in an unusual situation? How profoundly will its exercise modify the organism? These are entirely different questions. They are *questions of fact* that must be determined by observation and experiment.

So far as Lamarck was concerned, there was apparently no intention here to call upon supernatural intervention or upon unknown principles and forces. It is sufficient to consider merely the common-sense implications of the fact that living things do really respond to external stimuli and to changed conditions in a more or less adequate manner.

The most frequently cited examples of the operation of this principle are those of the giraffe, of water birds, and of the snake. In the absence of grass and herbs a grazing animal will reach toward the leaves of the trees, and in stretching for food will gradually lengthen his front legs and his neck. A bird near the water, unable to find sufficient food on the land, will wade into the shallows and either attempt to swim, stretching the toes apart, or attempt to keep its body out of the water, stretching its legs. The obvious effect would be the formation of webbed feet in one case and of long legs in the other. A four-legged lizard, crawling through tight places and into narrow holes, will gradually slough the legs and lengthen the body into a snake-like form. It may be difficult to consider these examples without having them seem absurd; but this is only because many of us happen to know that the activities and "needs" of these hypothetical cases do not work out that way. Giraffes do reach the leaves in the trees, but those fed on hay from the ground get to be just as tall. Hens do not acquire webbed feet or long legs when placed in water, even when thrown into the water fresh from the egg. Lizards do not become more snake-like when raised in the neighborhood of holes or close vegetation. Animals do, however, make in new situations responses that are adaptive — so effective, in fact, that one cannot but be impressed with their seeming intelligence or purposiveness. A description of such an adaptive response does not then seem so absurd.

We may take by way of illustration the fact that an animal infected with the germs of diphtheria and becoming sick may, instead of succumbing to the disease, recover and then remain indefinitely immune to further attacks. What

happens in such a case? The pathologist may be content to tell us that the tissues of the body, or perhaps certain cells only, elaborate an antitoxin, a something that counteracts or neutralizes the poison of the diphtheria bacillus. How is this result brought about? Does the organism's "need" automatically guide the physico-chemical reactions of the white blood cells? Is there perhaps an "instinct" for responding appropriately to such a stimulus? We have already intimated that, waiving the assumption that the giraffe's stretching will actually lengthen his neck, we have still to find out how the animal comes to stretch at all. The primary disposition to respond appropriately to the situation is after all an inseparable part of our conception of living things. We may therefore grant Lamarck's premises, even if we reject his conclusions, pending further information regarding the source and the mechanism of this primary responsiveness.

It is not necessary to assign to Lamarck's second law an anthropomorphic intent; and Lamarck himself recognized that the formulation does not apply to plants and to many animals, although the distinction may not be due, as he supposed, to the presence or absence of a nervous system.

The Essence of Lamarck's Teaching

The center of controversy in Lamarck's doctrine is found in his fourth law: whatever modifications are brought about in the individual in the course of his development are inherited by his offspring. This principle is briefly described as *the transmission of acquired characters,* in ordinary discussions. It is obvious that *if* the modifications which the individual animal undergoes because of its response to the living requirements do accrue to the benefit of his offspring, adaptation of species is easily explained. Whatever it is that the individual does and that enables him to continue alive has the virtue of a good habit, or increased skill, or greater strength. According to this idea the children of educated

people ought to start out with an improved intellectual mechanism, but not necessarily with the direct result of learning, or increased knowledge. The horse that has been trained should give birth to swifter colts. An animal that has recovered from an infectious disease should have more resistant offspring.

From the point of view of logic, nothing could be more plausible. Indeed, Herbert Spencer and other supporters of Lamarckism laid the greatest stress upon this. No theory could more simply explain the facts, the actual fitness of living species to the conditions under which they live, to the getting of food, to the escaping from enemies, to the resisting of cold or heat, to the finding of mates, to the shielding of the young, and so on. The whole world of life does in fact behave in every way *as if* each individual born brought with him as part of his innate equipment the very qualities and capacities that a mature individual seems to acquire in the course of his experience with the environment. The theory is sound, argues Spencer, since (1) it explains adequately the observed facts; and since (2) evolution of forms with progressive adaptation is otherwise inconceivable. In other words, it *must* be true because it stands to reason, and because without this idea we are at a loss to understand what happens.

Postulates versus Facts

It needs repeatedly to be pointed out that although much of our reasoning is of precisely this form, it is utterly unreliable as a means of discovering the truth. We can all recognize the fallacy in primitive myth and current superstition, when they take this form. Sol must drive his chariot over to the east during the night, otherwise the sun could not rise the next day. Ghosts must consist of material substance, otherwise we could not see them. A magnet must have intelligence, otherwise it could not know iron filings from sawdust. The earth must be flat, otherwise things

would roll off the surface. Yet Lamarck attempted seriously to avoid unwarranted assumptions and mystic factors. Lamarck was apparently unaware that his fourth law was the searching crucial one in his whole theory, taking the statement to represent a fact. The discussions in his own lifetime had to do chiefly with two other points — first the general theory that evolution did actually take place, and second, the process by which the individual acquires fitness during his lifetime. As a result, the "inheritance of acquired characters" remained without systematic criticism for nearly two generations. Darwin accepted it without hesitation; Samuel Butler knew it was so. Richard Semon noted the close parallelism between a modification in response to the environment and memory. The organism is impressed by everything that happens to it, and by every response that it makes to outer stimuli. It does actually become stronger and more skillful, tougher or swifter, as a result of its experience. In other words, it learns as a child learns. More exercise, more experience, means more memories or deepened impressions, or better and more reliable habits. From this it is but a short step to recognize in the inborn responses and ability to adjust — inherited habits.

Lamarck, as we have seen, distinguished between the adjustments of plants and lower animals, which he considered, so to say, imposed reactions, and the adjustments of higher forms, which he considered manifestations of intelligence. The former class of responses could not be inherited, or at least might not. The latter, however, through effective, purposive effort brought about appropriate changes in bodily structures and functions. The instinctive (that is, unlearned) behavior of subsequent generations are equally effective or purposeful, but do not involve anew the conscious or intelligent striving. Hence, instinct is to be considered as inherited experience — in Lamarck's phrase, the result of lapsed intelligence. With the exercise of instinct, the mechanism improves and each succeeding generation transmits the quality in increasing

perfection. Herbert Spencer, accepting Lamarck's essential principles, would have nothing to do with the tendency toward perfection, which was for him, as for many thinkers who accept it, a mystical entity. It is explained by Lamarck, however, in a common-sense way — granting, that is, the transmission of acquirements.

There is the possibility that under the influence of the encyclopedists and of the current enthusiasm for universal uplift, Lamarck adopted the principle of progressive improvement from the model of social or cultural advancement. It is sufficient for the present, at any rate, to note that the improvements which he used as illustrations can be readily enough explained without assuming the transmission of modification. If the children of "educated" parents learn more easily than the children of illiterates it may be because the stimulation for learning comes to them earlier in life, or because they come of a stock that takes kindly to intellectual pursuits. The ~~colt~~ young horse of the well trained mare runs faster than others not because the mother was trained, but because he is descended from ancestors who have it in them: the training brought the capacity to the surface. The son of the blacksmith is more muscular than the son of the vicar because he belongs to a family given to muscular development, and so on.

The Germ Plasm

The first systematic attack upon Lamarckism came from the studies of the German biologist, August Weismann, who in 1893 formulated his theory of heredity in his book *The Germ Plasm*. In this Weismann developed a sharp distinction between the protoplasm which makes up the body of a plant or animal, and that which passes from generation to generation in the eggs and sperms. The latter he called the germ plasm. In one-celled animals, like ameba or paramecium, each individual gives rise to two by the process of cell division. The protoplasm, assimilating food and increas-

ing in mass, continues from generation to generation: barring destruction by enemies or outside agencies, Weismann pointed out, *such protoplasm is virtually immortal.* The specialized tissues of plants and animals, on the contrary, while they attain their growth and development through cell division as in the case of a collection of the primitive organisms, reach a definite limit in their reproductive abil-

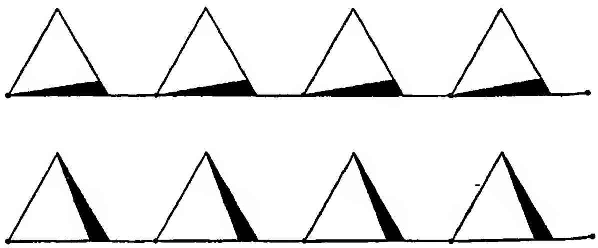


FIG 83 RELATION OF PARENT TO OFFSPRING

According to the older theory (lower row), the egg develops into an individual (represented by the entire triangle) and a portion of the body then becomes differentiated as reproductive substance, the black area. In reproduction, a portion of the germinal material becomes detached from the parent and develops into a new individual According to the later theory the egg developing into an individual divides into two series of cells, one of which forms the soma or body, the white area, and the other the germ material, the black area of the triangles. According to the older theory the body of the hen gives rise to the egg According to the newer theory, the hen, in developing from the egg carries some of the germ plasm within her body, protecting it, nourishing it, and passing it on eventually as more eggs to develop into more individuals germ plasm has a continuous history with offshoots from time to time in the form of a body.

ity: *their cells have acquired mortality.* Such cells make up the nerves and the skin, the bones and the muscles, the glands and the gristle of an animal. The only cells of a mature animal that retain the immortality of the species, the capacity to carry the strain forward in time, are the germ cells.

To explain the relation between the immortal germ plasm and the mortal soma or body plasm, Weismann pro-

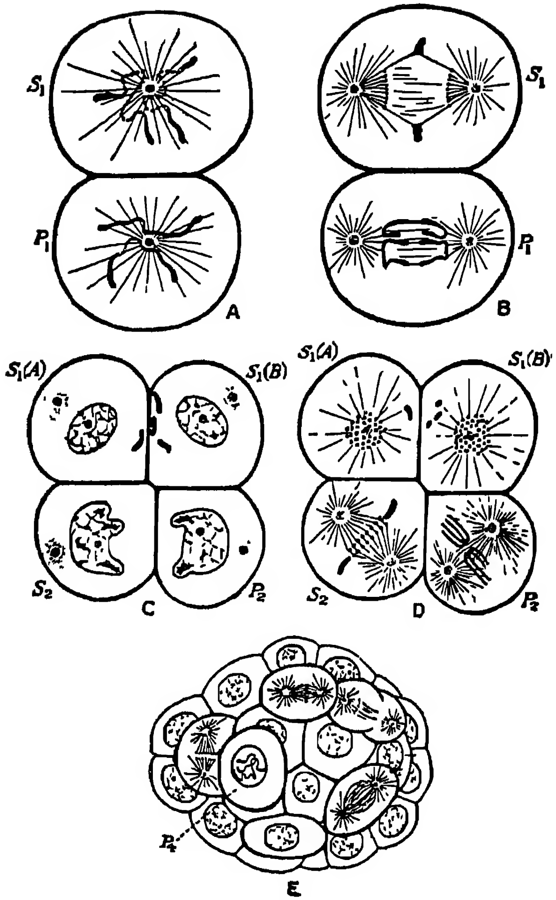


FIG. 84. THE GERM-TRACK IN THE THREADWORM ASCARIS MEGALOCEPHALA UNIVALENS

In the two-cell stage, *A*, the two chromosomes in one of the cells, P_1, are intact, whereas the chromosomes in the other cell, S_1 break up so that when the cell division leading to the four-cell stage, *B*, is under way a portion of the chromosome material is left outside the spindle, S_1 In the four-cell stage, C, the broken-off ends of the chromosomes of the cell S_1 are left outside the nucleus, S_1 (A) and (B), whereas the chromosomes of the other two cells, derived from P_1, are intact, S_2 and P_2. In the next division, *D*, the chromosomes of P_2 remain intact, but those of S_2 again break up In later stages this process of fragmentation is continued, *E*, and the one cell, P_4, that retains the original chromosome organization becomes the mother-cell from which the gonads are developed After Boveri, in Agar's Cytology, copyright by Macmillan & Company, Ltd, from Babcock and Clausen, Genetics in Relation to Agriculture, published by McGraw-Hill Book Company.

posed this interpretation: It is the germ cell that gives rise to an individual body, not the individual to germ cells. It is false to say that a plant or an animal produces eggs or sperms, the egg or sperm plasma is already present at the birth of the individual (see Fig. 83). According to this view, the germ plasm is continuous and the soma is in each generation an offshoot or branch from this immortal stream of life. The living matter of the individual is unable itself to continue the species, but it serves as an instrument for the germ plasm, shielding it and supplying it with nourishment and an opportunity to multiply.

When Weismann proposed this theory he was unable to say definitely whether or not the germ plasm does actually behave in developing individuals in accord with this supposition. Rudolf Virchow, the anti-evolution pathologist, had already shown, even before the publication of *The Origin of Species*, that there is a continuous cell-lineage in the development of the body, and not, as earlier observers had supposed, a formation of cells around dispersed centers of organization. The cells are related to one another. The continuity of the germinal protoplasm had been announced by various students, but the significance of this continuity was first pointed out by Weismann on purely theoretical grounds. It has since been shown that in many plants and animals a " germinal track " does actually become separated early in the development, and that it remains distinct from the body cells to the time of sexual maturity (Fig. 84). At any rate, as the theory became clarified, it set up an insuperable obstacle to the acceptance of the doctrine of inheritance of acquired characters, for Weismann's theory left no place for a mechanism whereby the changing soma could influence the germ plasm. The individual is like the parent, according to Weismann, not because the parent has molded the germinal material in his own likeness, but because *the parent and the offspring both derive from the same stream of continuing germ plasm.*

Problem of Inheritance

The difficulty of explaining how the characters of the organism can be transmitted by the minute germ had led to numerous theories, among them one by Darwin, who supposed that tiny gemmules were produced by each kind of organ or tissue cell and brought by the blood to the gonads, where they were organized into the eggs or sperms. This theory of pangenesis did not long receive serious consideration, but represented a thought that might have helped Spencer establish the theory of transmission of modifications by providing it with a conceivable mechanism.

Weismann's theory, supported by many facts as well as by speculative argument, at once reopened the discussion of the inheritance of the effects of use and disuse, and of other environmental influences. Weismann himself cut off the tails of rats, both male and female, for over twenty generations, in the search for evidence of transmission. Facts regarding the failure of mutilation and analogous modifications to reappear were accumulated. These negative facts, however, were not taken seriously by the Lamarckians. They were moreover irrelevant, since the distinction between a *mutilation* or imposed alteration and a *modification* resulting from the organism's own activities may be valid and important. Weismann and his followers could continue to challenge their opponents to produce positive evidence, while relying for their rejection of Lamarckism upon logic. It is *inconceivable,* is the argument, that changes in the soma should influence the germ as Lamarck's theory required. It must be admitted that this kind of reasoning sounds very much like the argument, modifications must be inherited, otherwise *we cannot imagine* how evolution takes place.

Objections to Weismann's Position

There are two serious objections to the absolute separation, in theory, between germ plasm and soma. There are

many plants which are able to reproduce themselves completely from only a fragment of a specialized organ. The many varieties of the common house plant begonia regenerate very rapidly from a bit of stem or leaf (Fig. 85). A plant thus grown from a bit of the vegetative body eventually produces flowers with effective sperms or eggs — that is to say, *germ plasm seems to be produced from specialized soma material.* In earthworms and other comparatively simple animals an analogous situation may arise. These animals can regenerate a complete individual from a portion of the body. The regenerated individual may then bear functional ovaries or spermaries.

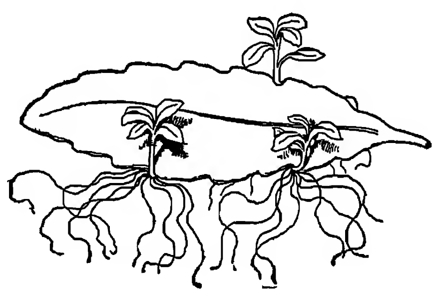


FIG 85 REGENERATION IN PLANTS

If a leaf, or even a portion of a leaf of bryophyllum or begonia be placed on damp earth or sand, tiny roots will form at certain points along the border, buds will be produced and after a while there will be one to several complete plants which may grow into mature individuals From Gruenberg, Biology and Human Life, published by Ginn & Company

A second objection comes from the observed unity of the organism. Each organ is influenced by what happens to every other organ. We know today that the hormones discharged by the organs of internal secretion produce profound effects in remote parts of the body. It is difficult for us to believe that the germ remains unaffected by what happens to the body. It is at least as inconceivable that the germ cells should escape such influences as it is that bodily changes should modify the germ cells.

The Weismann objection to Lamarckism is nevertheless on the whole sound. Recent discoveries regarding the mechanism of inheritance, especially the relation of the chromosomes to the transmission of particular characters, go far to support the essential features of Weismann's theory,

even if they do not solve the theoretical problem presented by regenerating leaves and earthworms. We do not know how eggs or sperms arise in specialized tissues that seem to be without embryonic or germinal cells. We do know, however, that the germ cells carry within themselves whatever material substance or structure determines the inheritance of the individual.

What Are Acquired Characters?

A more direct approach to Lamarckism is to be found by examining actual facts. First of all it becomes necessary to make more precise the distinction between "acquired" characters and others — presumably inherited. A person learns to play the piano; his twin brother does not. In this case ability to play the piano is acquired. Disregarding for the sake of the discussion the possible influence of the other parent, will the children of the first play the piano more easily, or learn to play more easily, than the children of the second? This is the usual form of the issue.

Is grayness of hair in old age an acquired character? Certainly, one is not "born with" gray hair. Is the milk production of a prize cow an acquired trait? Is the pigment on the upper surface of a fish, or the whiteness of the belly? Are we to consider the differences between two groups of plants grown from the same pod of seeds, under two sets of conditions, acquired characters? Is defective bone development in a rachitic child acquired?

We could go on endlessly only to find increasing difficulty in making the distinction between inherited characters and acquired ones. As we have already seen, however, the distinction itself is impossible because it rests upon an unsound assumption (see pages 166 ff). This is the assumption that a given character in an adult plant or animal is due to degrade entirely to heredity *or* entirely to environment. Deprivations in the form of mutilations or injuries, and acquirements in the form of habits or knowledge, may be considered in

a strict sense as exclusive results of environment. Yet even in such acquirements it is obvious that an identical environment cannot produce the same results in different types of individuals.

Organisms are modified by cutting off tails or limbs, piercing eyes or ears, repressing growth through undernourishment or drouth, distorting structures through cramping by corsets, stiffened with whale bone shoes, head-boards. Such changes, however, are not strictly speaking modifications in any organic sense. They were not so considered by Lamarck, although uncritically accepted as such by many of his followers as well as by opponents of his theories. Yet the moment we seek for a true example of organic modification — one due, that is, to the dynamic responsiveness of living matter — we have to revise our antithesis between heredity and environment.

The minnow inherits the capacity to develop into a two-eyed fish. That is true but it can become a two-eyed fish only in a certain kind of ocean. In a different environment it becomes normally, that is, because of its inherited constitution, a one-eyed fish (see page 172). A human infant is born with the capacity to develop a certain grade of intelligence. It can attain to that intelligence only in a special kind of environment — including iodin salts and social stimuli. We discover what is "normal" from the occasional appearance of abnormalities. Under routine conditions we take for granted that variations are due to "heredity." Differences which appear after the diffusion of a homogeneous population into a variegated environment are attributed to the latter. The essential fact that stands out is this: *The characters actually present represent the reaction of a given heredity to a given environment.* The identities observed generation after generation depend, as Weismann argued, upon the common source in a continuous stream of specific germ plasm; but these repeated identities are possible only in a uniform environment (that is, uniform with respect to the essential factors).

Confusion from Selected Cases

Every community has its share of old wives' tales illustrating the dire consequences of throwing strawberries at or exhibiting mice to pregnant women. It would be unscientific to dismiss these tales out of hand, along with ghost stories and horse-hairs that turn into wriggling worms, simply because they do not fit into our preconceptions as to how things work. Of the older tales we can at most say that the observations may have been faulty, the records inadequate. In more recent times, however, many of these stories have come under critical notice. Whether they are treated statistically *en masse*, or analyzed in detail, the only possible conclusion is that there is nothing in them — so far as concerns the transmission to offspring of maternal impressions. In one lying-in hospital over ten thousand mothers were given an opportunity to relate events in their pregnancies that might have influenced the unborn child. In no case could markings or malformations or minor abnormalities be anticipated on that basis.

There are other tales that have to do with the transmission of acquirements — not indeed the inheritance of wooden legs, for example, but the inheritance of a malformation at a spot where the father had burned his finger, or shortsightedness in a child subsequent to the father's having studied too hard while at college. Spencer cited the frequency of shortsightedness among the Germans as an example of the transmitted effect of using spectacles excessively — and the Germans used spectacles so much because they were so studious. There are also examples of the reappearance of other unusual traits in successive generations. These have all been offered, not to prove that acquired modifications are transmitted, but merely to illustrate what we thought we already knew. There are in these cases two kinds of misunderstanding, or at least the conclusions may be unsound because of two types of fallacy.

It is assumed that the trait in question is actually a modification — shortsightedness, for example, or bleeding (hæmophilia, see page 264), or hornlessness in cattle. A man has a severe nosebleed — almost dies, but not quite; it is a dramatic episode and not easily forgotten. The circumstances leading to the nosebleed are remembered. Is it any wonder that, when years afterward his grandson repeats the experience, people will recall and point to the transmitted effect of a severe blow on the nose? It happens that defective clotting of blood is a physiological condition the inheritance of which has been pretty thoroughly studied. The conditions appear to be a "sex-linked recessive" and one could predict the manifestation of the trait in a family of known genetic composition, except for the circumstance that human families are ordinarily not large enough to permit of statistical treatment. It happens also that hornlessness in cattle has appeared as a mutation (not a mutilation) and reappears in heredity as a Mendelian dominant.

The other assumption that invalidates many of the illustrations of the supposed law is that the reappearance of a modification is necessarily evidence of its inheritance. Longevity may be, probably is, the result of numerous inherited factors. Being killed by an automobile at forty years of age is probably not, although there are cases in which father and son terminated life in similar fashion at about the same age. A large class of recurrent modifications is found in the repeated appearance of an infectious disease. For centuries it was common to see pock-marked faces; and then such faces would be borne by all the members of a family. The modification, however, was a fresh one for each individual. Other effects of disease would fall in the same class.

Disease and Heredity

The fact that one or another disease "runs in a family" has also given rise to misunderstandings. The physician to-

day makes a distinction between inheriting a disease and inheriting a disposition. This is a valid distinction even if the medical profession is not in possession of all the relevant facts. Tuberculosis illustrates the point because it is so widepread and has been so extensively studied. If you take an infant from a family that has been tuberculous for generations there is a chance, in favorable surroundings and away from infected persons, to raise it to maturity without infection. The disposition or susceptibility is there; but the disease cannot manifest itself unless there is also an infection. Whole communities have been decimated by an infection imported from without. The end results show that the people were susceptible, but they were free from the disease for generations because the specific infectious agency had not come into their lives.

If a family is not exposed to infection for several generations we have no way of knowing its susceptibility. Statistical and epidemiological facts would indicate, however, that resistance to a particular disease, or special susceptibility, is inherited. Certain factors of musical ability seem to be inherited among people who have no musical training, living in communities having no musical traditions. Under favorable conditions — that is, suitable stimuli — some of these will manifest themselves, whether the parents had the opportunity to cultivate them or not.

Proving a Negative

One of the difficulties with the doctrine that the results of use and disuse are inherited is the circumstance that its opponents are trying to prove a negative. From the nature of things, this is an impossibility. It is almost as futile as it would be for a monist to attempt to prove that the earth was *not* created in six days or sixty. At the same time there has been accumulated a body of facts that militate against the Lamarckian assumption, and render it unnecessary for logical purposes. As we have seen, the transmission of char-

Photograph from American Museum of Natural History

August Weismann

Germany 1834–1914

acters or capacities is by way of the germ cells, and more particularly by way of the chromosomal mechanism of the germ cells. Now it does not bring us anywhere to argue that we cannot conceive how a change in bone or muscle, resulting from exercise or from disuse, can reach the chromosomes. This helps no more than the argument that we cannot conceive how evolution can take place unless the favorable responses do actually come to be transmitted. It does help, however, to try to find out whether or not germinal material is modified, or under what conditions it becomes modified. On this question then there is a great deal of dependable and significant evidence.

There is a large body of experience in the grafting of plants. In this common horticultural practice the cut base of a twig of one variety of plant (say a plum) is inserted among the living tissues of an older branch of a different variety. The artificial wound is covered and allowed to heal. The scion or engrafted limb continues to manifest the distinct qualities of the tree from which it was taken in leaf, flower, fruit. The stock or the larger plant that now supports the graft also continues to live its life, seemingly unaffected by the intruder. Luther Burbank had at one time a plum tree bearing some 600 distinct grafts; and there was no indication whatever that this close intermingling of tissues affects one or the other member of the union.

What would seem to be a crucial experiment in animals was performed by Castle and Phillips on guinea pigs of known pedigree (Fig. 86). A female albino was spayed—that is, her ovaries were removed. Then the ovaries of a black guinea pig were engrafted in their place. After the tissues were healed, the white female was mated with an albino male. Let us recall that in these animals albinism or the absence of pigment is recessive, so that two white parents always produce white offspring; and that the dominant character, pigmentation, will appear in the offspring even if only one of the parents is a pure black. In this cross (between an albino male and an albino female carrying ovaries

from a black female) *all the offspring were black.* That is to say, the white female did not modify the germ cells produced in the foreign ovary which she carried in her body. Nothing in the germ cells derived from a black female was influenced by the intimate lodgment and nourishment in the body of the white female. The eggs continued to "transmit" whatever it was they represented in their original

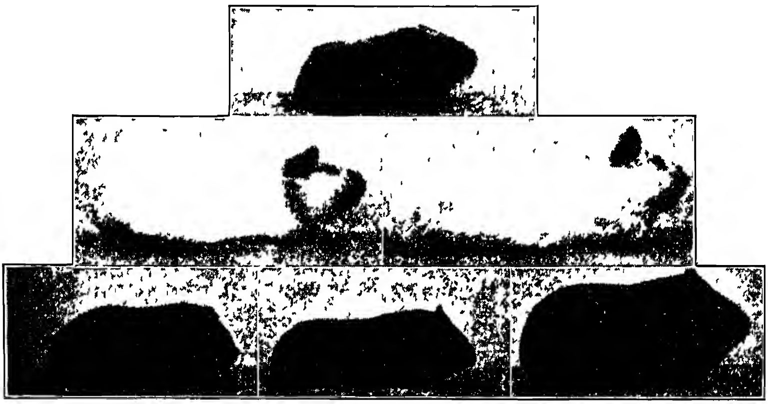


FIG. 86 THE FOSTER MOTHER AS ENVIRONMENT

The black female, top, had her ovaries removed and engrafted in the albino female, left, which had been previously spayed After recovery of the albino, she was mated with the albino male, right. The offspring, bottom row, were all black and indistinguishable, as to pigmentation, from the grandmother who had supplied the eggs The maturing, fertilization and development of the eggs seemed to be unaffected by the character of the foster mother, so far as the pigmentation is concerned After Castle and Phillips, photograph by courtesy of Professor W E Castle

position in the body of the black guinea pig. Further breeding and other experiments support this view: *the germ cells are not modified by the body.*

The thousands of experiments that followed the rediscovery of Mendel's principles have still further confirmed this conclusion, and supported Mendel's theory of the purity of the germ plasm. The most intimate protoplasmic union that we know is that between the chromosomes of the sperm and those of the egg. Yet after this union it is possible for

maternal and paternal contributions to remain distinct, as is shown by the segregations in the progeny of hybrids. Hybridizing brings into the germ plasm new combinations, but the alternative traits do not affect one another. The genes, or determiners, or factors present in the germ cells retain their individuality from generation to generation.

With negative results from experiments in grafting and in genetics, it is possible at most to conclude that the transmission of acquired characters is "not proven." While the burden of proof rests upon those who believe that there is such transmission, those in possession of the negative evidence must not be too positive in their denials. It should be recognized, however, that such positive evidence as has been offered can quite as well be explained by known principles of genetics as by the Lamarckian principles.

Experimental Transmission of Modifications

In more recent times biologists have found it necessary to discriminate, in considering this problem, between a possible *effect upon the germ plasm,* and the possible transmission through the germ of an *effect upon the body.* This is an important distinction, for we have already seen (page 164) that radium and chemical processes can modify the germ cells. In such modifications of the germs, however, we never see the reproduction of a character that has been induced in the parent organism. Alcoholism, for example, has resulted in defective offspring: but the effect in the offspring, conceded to result from the alcoholizing of the parents, is not the same kind of effect as is produced in the parent by the alcohol. Aside from the fact that in these experiments the results were always more or less injurious rather than adaptive or useful, they are of a distinct order in the germ and in the soma. These facts have given rise to the theory of *induced* changes in the germ cells. The problem then takes the form of asking whether changes induced

by the environment are ever parallel in parent and offspring. Examples of such parallel inductions are seen when plants are stunted by unfavorable living conditions, with the result that their seeds are exceptionally small. The next generation then starts out with an original handicap of a low food reserve. In some animals it has been possible to handicap the offspring by exposing the parents to extreme cold, or to injurious chemical action. Such parallel inductions, however, fail to establish the transmission of acquired characters.

An Austrian, Paul Kammerer, published the results of experiments with black and spotted salamanders, in which he believed to have demonstrated the transmission of modifications. These animals differ somewhat in their habitats, the former being an alpine form and the latter occupying lower regions. In both species the eggs develop within the body of the mother, the development proceeding farther before birth in the black salamander. By transposing the living conditions, Kammerer succeeded in modifying the breeding habits of the animals, and the modification increased progressively for several generations. From these results Kammerer argued the cumulative transmission of modifications; but biologists generally, however, are not convinced by the evidence, for this type of alteration in habit is well known among plants and animals, and is usually reversible through a further reversal in conditions. Other experiments by Kammerer had to do with enlarging the yellow area at the expense of the black, in the spotted salamander, by keeping the animals (that is, the parents) in a yellow box. Aside from the short duration of these experiments, and the small numbers of animals employed, there is the serious defect that there were no pedigree or quantitative studies to determine the normal range of fluctuation in the yellow spots. These experiments appear to be convincing in proportion to one's preconceived bias toward or away from the general doctrine of the transmission of the effects induced by the environment.

Guyer's Experiments

The most impressive experiments in this field have been carried on in this country by Professor Michael F. Guyer of the University of Wisconsin and his associates. These consisted essentially of an attempt to influence the development of rabbits within the womb of the mother by introducing into the pregnant mother's blood specific substances calculated to affect a specific part of the organism. The most definite and the most consistent results were obtained by injecting a special serum made from the blood of hens that had been previously sensitized to the lens of rabbits' eyes. We have seen (page 61) that the introduction of a foreign protein will bring about in the blood of animals certain changes that bear a specific chemical relationship to these foreign substances. Guyer injected a pulp made from the eye-lens of rabbits into the blood of hens. He thus obtained a serum that had specific properties which showed themselves in actually dissolving eye-lens substance.

Now the introduction of this serum containing the anti-lens substance into the blood of pregnant rabbits sometimes proved fatal and sometimes caused injury to the adult rabbit; but never produced any effect upon the eyes. Moreover, these injections did not affect the eggs, since normal rabbits were subsequently bred from females thus treated. When, however, the injection was made into rabbits pregnant from ten to fourteen days (the period during which the embryo eyes are developing) definite results appeared. Of the surviving baby rabbits, of which there were sixty-one, four had one or both eyes clearly defective, and five others had more or less serious abnormalities of the eyes. Among the hundreds of offspring of other rabbits, similarly treated with ordinary fowl serum (that is, from fowls not specially prepared) and with other special serums, not one ever showed such eye defects; and none of the treated mothers showed such eye defects. Whatever the serum did, it acted apparently upon the embryo rabbits while still in the wombs of their mothers.

This special effect was produced only at the time that the eyes were in process of formation.

The startling part of this experiment is still to come. The rabbits thus born with defective eyes were allowed to grow up and to breed. For eight generations they continued to reproduce defective eyes, in the manner of a Mendelian recessive, so that it was possible to establish a " pure " strain showing these defects. There would seem here to be a case of parallel induction by the action of a highly specific substance. It is to be noted, in considering this experiment, first, that Stockard and others were able to induce eye defects by using non-specific substances, such as alcohol; and second, that Guyer and his associates failed to produce other specific effects although trying various kinds of special sera. Further confirmation of these results and their extension promise at present to give us the most direct answer to the general question, Can a force or agency acting upon an organism and producing alterations in its structures and functions produce in the germ cells such changes as to lead in subsequent generations to the development of similar modifications *without the repeated action of the original modifier?*

Pavlov's Experiments

The supporters of the Lamarckian hypothesis received overwhelming encouragement for their position a few years ago, when the great Russian physiologist Ivan Pavlov visited this country. On the eve of his departure Pavlov referred casually to some experiments in process at his laboratory in Leningrad, where white mice are being conditioned to respond to the sound of a bell as they normally respond to the presentation of food. According to Pavlov the normal mice take about three hundred trials to substitute the artificial stimulus for the natural one for arousing the movement toward food. In the second generation the same result was obtained in about one hundred trials, and subsequent genera-

tions bettered the instruction of their parents until the fifth generation could learn to run for food on hearing the bell after only five trials! Particulars were promised, but so far have not been forthcoming. Serious doubt is cast upon this report not only by those whose experience is with the biology of white rats, but also by those whose experience is with the learning processes in animals or with the genetics of mammals. For the present, the most that can be said about the prematurely announced results of the Pavlov experiment is that they are of tremendous importance — if true.[1]

Conclusions

While the doctrine of transmission of the effects of use and disuse, or of the effects of response to environment, remains unproven it does not follow that it is impossible. With all the facts of genetics and reproduction consistently against this view, it may nevertheless contain a trace of truth, at least in some modified form. Indeed, the relatively few biologists who are inclined to favor the view are not Lamarckians, but Neo-Lamarckians, rejecting some of the crudities of the earlier formulations, and basing their expectations on the fact that germ plasm must be, like other protoplasm, plastic and subject to change by suitable forces.

For the present the status of the discussion may be summarized as follows:

1. Living things respond to environmental changes and stimuli; and some of the results of such responses are adaptive.

2. The characters or functions present in a developed

[1] In an informal statement made at the time of the Thirteenth International Physiological Congress, Boston, August 1929, Pavlov explained that in checking up these experiments it was found that the apparent improvement in the ability to learn, on the part of successive generations of mice, was really due to an improvement in the ability to teach, on the part of the experimenter! And so this "proof" of the transmission of modifications drops out of the picture, at least for the present

organism cannot be ascribed as due exclusively to inheritance or exclusively to the environment.

3. Developed characters are never transmitted as such in heredity.

4. The general constitution is not changed by the development of characters in the individual.

5. Germ cells may be influenced by environmental factors acting *through* the body, but are not influenced by the reactions of the soma to the same environmental factors — or at least not in the sense of including a similar development in subsequent generations.

Chapter 11

The Theory of Natural Selection

THE publication of Darwin's *The Origin of Species* in 1859 produced a tremendous impression upon the intellectual life of Europe and America. The book accomplished two distinct purposes remarkably well. The first of these was to make the general theory of the transformation of species appear reasonable on the basis of a vast accumulation of facts from comparative anatomy, embryology, geography and paleontology. Darwin made it clear at the time that there was no rational explanation of existing species of plants and animals other than the assumption *that there had been descent with modifications.* Darwin himself did not use the word evolution. He did make out a good case, however, for what we now call evolution of species, as against the idea that each type was specially created in the first instance.

The second purpose which the book accomplished was to work out a theory to explain *how evolution of forms could have taken place* through the action of intelligible natural forces. This theory of natural selection seems to furnish a mechanism in accord with common sense and common experience. Many were inclined to accept the general theory of descent but were prevented by their inability to see clearly just how in the course of generations plants or animals could become differentiated from their ancestors. These were enabled by Darwin's theory to accept wholeheartedly the general idea that evolution had in fact taken place.

Unfortunately, the two purposes became inextricably confused in the minds of most people. As a result, clear

thinking on both problems has been obstructed. It is necessary for our purpose to keep distinct the general theory of organic evolution and Darwin's explanation, even if we learn about both out of the same book, *The Origin of Species.*

Malthus as Catalyzer

Darwin tells us in his *Autobiography* that after his return from a voyage around the earth as naturalist for *The Beagle* he started a set of note books on variations in plants and animals which had impressed him in the course of his journey. For twenty years he gathered material to prove that there had been descent with modification. He hesitated about publishing his results because he could not make up his mind just *how* transmutation of forms had come about. His health was such that he was compelled to live quietly in the country, being able to work only a few hours a day. Apparently, however, he was able to accomplish a great deal through reading, correspondence and observation of the living things in his garden and in the barnyard.

With the problems constantly on his mind, groping for some principle that would unify his vast accumulation of direct observations and of the recorded observations of others, he chanced to read Malthus's *Essay on Population.* The immediate effect of this, Darwin writes, was to clarify the whole problem. He proceeded immediately to shape his now famous theory of natural selection. The stimulating thought which he got from Malthus furnished Darwin the element of his theory which he called "the struggle for existence." Malthus pointed out that the tendency of each species of living things (particularly, for his purpose, of human beings) is to multiply in a geometrical ratio. The means of subsistence, on the contrary, can multiply only in an arithmetical ratio. We need not concern ourselves for the present with the fact that Malthus borrowed his ideas from Benjamin Franklin. Nor with the further fact that he got his facts wrong. The immediate result for Darwin

was to make him realize keenly the importance of the pressure of population in eliminating the larger part of each generation of living beings.

From this point the logic in Darwin's mind was perfectly simple: More individuals are generated than can possibly live out their lives. No two individuals are alike, and therefore some are better adapted to the living conditions than others. The pressure of population will eliminate the less fit. The survivors will be thus best adapted. The transmission of their favorable variations will result in the progressive adaptation of their descendants to the conditions of life.

Darwin had apparently accumulated all the essential facts for his purpose and needed only an illuminating flash to reveal the unifying principle that was to put everything in order. And this flash came from reading Malthus.

Wallace as Precipitant

Out in the East Indies the naturalist Alfred Russell Wallace, exploring and meditating, was preoccupied with the problem: How do living plants and animals come to be what we see them to be? He was impressed with the remarkable adaptation of many structures and forms to the needs of life. He was impressed by the great array of species intergrading so that he was plagued by the need to give each distinct species a name. They refused to remain distinct long enough to be labeled. Meditating in the jungle, he came to the conclusion that adaptation results from the elimination of the less fit. He could see the conflicts and struggles that destroyed the larger part of each new generation of eggs or seeds. He saw in the jungle the advantages and disadvantages of deviation from the type. He slowly worked out a theory of progressive adaptation through the elimination of the unfit in the struggle for existence.

Wallace thought he had a good idea and wrote it up in a long letter to Charles Darwin in England. This was so

much like his own ideas that Darwin was distressed. He consulted his friends and it was arranged that both theories should be presented before the Linnæan Society in July 1858.

Wallace's formulation of his theory forced Darwin to take action to get his own book into shape. While Wallace was continuing his explorations Darwin's book appeared.

The Logic in Natural Selection

Like Lamarck's theory published fifty years earlier, Darwin's was an attempt to explain natural phenomena by an appeal to natural laws. Darwin had been convinced of the transformation of species by his own observations in the field and by his later studies. He made it part of his task to show that all the facts of nature could better be understood under this conception than on the assumption of special creation. He spoke of transformation or of descent with modification rather than of evolution because the latter term carried with it at the time too many philosophical connotations. "Evolution" was being rather loosely employed to cover the whole of the historical process in the world of nature, and had been previously used for a special theory of embryonic development (see page 122).

In formulating his theory, Darwin attempted at each step to appeal to established facts and to common sense. The plausibility of his argument is due to this approach.

1. Everybody can see for himself that the individuals of any species vary.

2. It is a common fact of observation that it is impossible for all the eggs or all the seeds of any species to develop to maturity.

3. The struggle for existence is apparent on every hand; there is conflict not only between the members of a species, but also between one species and another for space, for food, for air, and so on. The individual is in constant

conflict with natural forces, that is, variations in moisture, in temperature, in light, and so on.

4. It stands to reason that the majority of each generation, destroyed before reaching maturity, consists of the individuals who are less favored in their structure or in their processes than the surviving minority.

5. Finally, it is a matter of common observation that individuals transmit to their offspring their characteristic traits.

Here then we have a common-sense explanation, relying upon commonly observed facts. The chief obstacle at the time to the general acceptance of Darwin's theory was the fact that most people were not prepared to think in transformation terms. Most of the lay criticisms that appeared were therefore directed not to the merits of the special theory but to the absurdity of reptiles coming out of eggs of fish or to the enormity of conceiving man to have "descended from monkeys." Most scientists, on the other hand, who were predisposed to assume the process of evolution, accepted Darwin's explanation as sound in fact and in principle.

The result, as has been indicated, was a dissipation of intellectual energies. The opposition concerned itself with *a priori* discussion of the general theory of evolution. The supporters of evolution had to waive a critical analysis of Darwin's theory of Natural Selection defending the general theory of evolution. For nearly a quarter of a century the research and speculation among biologists and paleontologists were chiefly directed to finding further illustrations and applications of Darwin's theory. Supplementary theories and amendments in detail were suggested but there was no substantial scientific opposition or criticism.

The Facts of Variation

Darwin accepted the existence of variation among the individuals of any species as fact. He recognized that there

were large departures from the parental type, such as sports, as well as the minute fluctuating variations. He did not make any serious attempt to differentiate the one class of variations from the other as a possible source of new varieties or species. Nor did he make any attempt to discover how far any kinds of variations were inherited.

We have already seen (page 185) that it is necessary to discriminate between continuous variations and discontinuous variations. This is not primarily a question of *degree* but a question of *genetic relationship*. The continuous variations are those that seem to be due to fluctuations in the conditions of growth and development. They are ordinarily very small, but occasionally rather large. The discontinuous variations, on the other hand, are departures from the parental type that are inherited in subsequent generations. These too may be trivial or rather extensive. We see among human beings, for example, variations in color of hair which may represent distinct hereditary manifestations; but we may see also variations in skin pigment which are due at the moment to the fact that some have had a longer vacation than others. Seeds from the same pod will yield plants of which the largest may be twice as large as the smallest, showing a wide variation in a non-heritable character. Among the fruit flies are found many variations of the wings. Certain of these, quantitatively no more striking than others, are definitely inherited, whereas other variations come within our notion of fluctuations.

Darwin, failing to make this discrimination, assumed that succeeding generations would inherit the favorable variations, in larger proportions. According to the Lamarckian doctrine, this ought to be true regardless of whether the variations were innate or the results of environmental stimulus. Darwin himself accepted readily enough the Lamarckian assumption of the transmission of acquired modifications, although he was rather disdainful of Lamarck's theory that such modifications could come about through "the inner strivings" of an animal.

Another assumption which Darwin made was that variation from type must of itself bring the individual some advantage or disadvantage. It stands to reason that if two things are not alike one must be better than the other. This is so "reasonable" that it is difficult for most of us to see that *it is not true*. We cannot hold this against Darwin when we realize that hardly any of us today can compare human beings without making invidious implications.

Over-population

The number of eggs or seeds produced by any living species is far in excess of what the environment can maintain as completed individuals. A large part of the food accumulated by a plant, for example, is converted into reserve for the embryo of the next generation. A large part of the food accumulated by a fish goes to the making of eggs. Conversely, a large part of the food consumed by plants as well as by animals is taken directly from the bodies of other living things. Eggs and seeds are particularly attractive as food for members of other species.

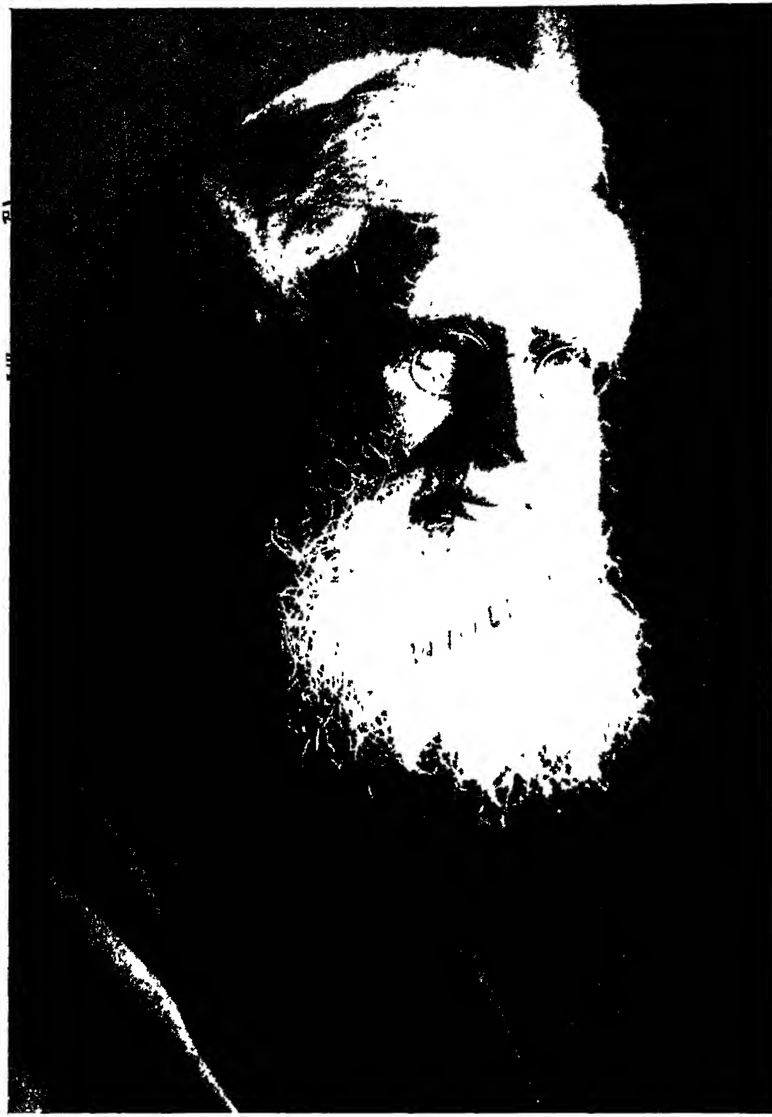
Darwin himself made a calculation to show the importance of geometrical increase even in such a slowly breeding species as the elephant. Suppose that the elephants begin breeding at thirty years of age and continue to ninety years, producing in the interval six young, and that each survives to the age of one hundred years. These are all very conservative estimates. There would then be living after 740 to 750 years *nineteen million descendants of a single pair*. Smaller animals breed much more rapidly and the ratio of fertilized egg or seed to surviving adult will in some species be well over a million. Dr. Punnett had occasion to study some rotifers, microscopic animals, through sixty-seven generations. Allowing an average of thirty eggs for each reproduction, he showed that if every individual were allowed to live out its life and reproduce, there

would have been formed in less than one year a mass of protoplasm greater than the probable limits of the material universe.

The world is so constituted that it is simply impossible for the descendants of any pair to survive and reproduce themselves in this geometrical ratio. There are too many other living things conflicting with this inner urge to multiply. There is not standing room for all of one generation. This tendency to multiply out of all proportion to the possibilities of survival alarmed Malthus. It revealed to him the wisdom of a providence which added famine, pestilence and war to the equipment of the universe, to prevent the dire disasters that might otherwise ensue from an unrestricted propagation! And it was this flash of insight that gave Darwin his clue to the mechanism of evolution.

Under the artificial conditions of stock raising and agriculture the multiplication of any species is regulated in accordance with the means of subsistence, available space, shelter, and so on. In keeping a population down to manageable dimensions the breeder also decides which of a mixed group are to be the progenitors of succeeding generations. The individual plants and animals under these artificial conditions are shielded from the severities of the struggle for existence which plants and animals in "a state of nature" have to undergo. On the other hand, restricting propagation to the selected few leads to wholesale extermination of hereditary lines.

If the rate of reproduction in plants and animals were a very small fraction of what it is, so that the population at a given time might just barely reproduce itself in the following generation, there would be no selection. The weak and the strong, the slow and the swift would equally well reproduce themselves and maintain themselves. It is the fact that the vast majority of the generation simply must be exterminated that makes possible the discriminating process which Darwin came to call natural selection.



Elliott & Fry

ALFRED RUSSELL WALLACE

ENGLAND 1823–1913

The Struggle for Existence

The process which has been figuratively described as the struggle for existence is a necessary part of our concept of living things. As already indicated (pages 147 ff), the maintenance of protoplasm involves constant adjustments and re-adjustments to the environment, which in turn is a constantly changing medium. The need for air, for example, involves more and more complex arrangements in the evolution of life. Although oxygen itself is plentiful, the increase in the total volume of living matter makes substantial inroads into the supply. Energy-consuming protoplasm could not maintain itself over a long period unless at the same time the supply of oxygen were replenished, as it is by the starch-building processes of green plants. Plants and animals do not manifest any obvious effort in breathing, and we therefore do not think of the struggle for air as part of the living process. When we consider food, however, the "struggle" is more apparent, since only a few of the very simplest organisms and those containing leaf green are capable of building up food material out of inorganic substances.

All species of animals and many species of plants are dependent for their existence upon the vegetation. To say that a given area can maintain a certain number of animals is to say that the plants in the territory are able to produce, in addition to what they need for their own maintenance, a surplus in the form of leaves, roots and seeds to feed these animals. Eventually all the energies of living beings on the earth are traced to the sunlight, since it is by means of sunlight that organisms containing leaf green are able to build out of raw inorganic substances the food essential to the maintenance of life. The struggle of the grass is for water and salts from the soil and of carbon dioxid and sunlight from above. Each individual seed is in conflict with hundreds of others in the effort to establish for itself a place in the sun and a foothold in the soil. We must remember that Darwin used the expression "struggle for existence"

in a metaphorical sense and recognized as clearly as any of us do today that a large part of the struggle is a passive one. He did not need to be reminded that seedlings do not poke each other with elbows or step on each other's toes. No one knew better, however, that the odds are all against the individual attaining maturity, if we start our calculations at the point where the individual comes into being.

It has been possible, in agricultural practice, to calculate from a study of the soil and of the climate the limiting factors for a given crop. We know in advance pretty closely how many stalks of corn (of a given kind) we can expect to come from an acre in a given location — that is, with a given soil and a given climate. We may calculate, therefore, the quantity of seed and the amount of cultivation that can be profitably applied to the area. Plants and animals that are not under cultivation seem to have no way of making these calculations in advance and they distribute their seeds and eggs in a most prodigal manner with the result that there is an incalculable waste involved.

From another point of view we may say that nothing is wasted since many of the seeds and eggs serve almost immediately as food for other species. Nearly all who start upon their development seem to be readily picked off by their enemies at one or another stage. There is also, from the point of view of preserving a species, the need for a margin that will fall on the proverbial stony ground. Eggs laid by amphibians and fish in shallow waters cannot in all cases be insured against the pool drying up. Mortalities have also been due to late frost in the spring.

The struggle for existence takes place between members of a species, where there are too many for the available space or food supply. There is also the conflict between one species and another for space, for sunlight, for water, for food. There is the struggle between each species and its prey or food supply on the one hand, and its enemies on the other. There is finally the struggle between each species and the inanimate factors of the surroundings.

Elimination Selective and Indiscriminate

The population tends to outrun the available food supply and other essential conditions of living. There is therefore an elimination of the superfluous which may be conceived to correspond to the relative ineffectiveness of the individuals in their struggle for life. Generally speaking, the fitter in this struggle will survive. The late frost will not kill all the individuals; those who can withstand frost are here the fitter and survive. Where foxes pursue hares, not all the hares are caught — the swifter ones escape. Conversely, not all of the foxes may get a meal — the slower ones would perish.

The struggle then affects every individual and results on the one hand in a vast slaughter, and on the other hand, in the survival of the superior.

Darwin recognized that the survival was not always an outcome of the struggle in any competitive sense. Vast numbers of seeds and eggs and young plants and animals are destroyed by their enemies as well as by changes in the weather, utterly without discrimination as to relative adaptability to living conditions. A whale will swallow a bushel of floating animal life that happens to be in his path, and the resulting destruction will fall like rain upon the just and the unjust. With all of this indiscriminate destruction of life the decision as to the ultimate survivors of each generation rests effectually, according to Darwin's views, upon *relative fitness*.

Natural Selection

Nobody had ever questioned the effectiveness of artificial selection in improving varieties of plants and animals. The practice has been widespread for at least two thousand years. Darwin, in using the expression " natural selection " recognized the essential differences between what happens in nature and what happens under domestication. In the

latter case there is a positive separation for further breeding of those individuals that show desirable traits. Under natural conditions the selection is entirely negative. That is to say, those that do *not* come up to a certain standard are ruthlessly eliminated by the many enemies and forces against which a living thing must struggle. Darwin made the further distinction between the conscious selection of the breeder and the ruthless destruction by nature, in which he refused to assume a conscious purpose. This is an important point which is frequently overlooked by the followers of Darwin as well as by his opponents and it was sometimes overlooked by Darwin himself. Darwin explicitly stated that he did not intend to personify nature. He recognized clearly enough that the personification of nature, in his theory of natural selection, would simply evade the responsibility for finding a scientific explanation of evolution just as did Lamarck's "inner strivings."

To postulate a conscious purposeful entity driving and guiding the natural processes leaves us without any need (and probably without any possibility) of searching further into causative relations. Every problem can be solved by assuming an unknown and unknowable principle whether we call it nature or divine intelligence. The scientist who adheres rigidly to the principles of his calling will refuse to consider such a solution, notwithstanding his frequent necessity of acknowledging his utter ignorance. Ideally, he would rather say frankly, "I don't know," than hide his ignorance behind a phrase which seems superficially to answer the question but which in reality says, "I don't know."

The doctrine itself is simple enough. Plants and animals vary. They cannot all attain maturity and reproduce themselves. They are destroyed and obstructed at every turn by a variety of forces and enemies. Those who do at last survive and leave progeny are those who *can* meet the severe demands which nature makes upon life. They are the fit. They are favored by nature in having been born with their useful factors or with the ability to meet the struggle

for existence. They are favored by nature by being allowed to furnish the next generation. The result is the separation from a mixed population of the relatively few individuals who are, all things considered, most fit under the circumstances. This is all there is to natural selection. This principle is so simple, it appeals so strongly to common sense, that for a long time it could not be questioned. People could doubt whether improvements had taken place in an evolutionary sense. People could say that the whole thing was impossible because God would not be so cruel as to make millions of plants and animals in order to destroy them for the sake of a few favored survivors. But the common sense of the argument remained. At any rate, the opposite is inconceivable.

Specific Characters Non-adaptive

Some naturalists brought up one objection to the theory which did not have much weight with the general public since it was largely technical. The taxonomists pointed out that the marks which distinguish one species from a different but closely related species are usually not of a kind that can have any conceivable value in a struggle for existence. There were slight differences in coloration or pattern, in the distribution of hairs, in the shape of one or another organ. These marks were fairly constant, and convenient for those engaged in classifying, but hardly of a life-and-death significance. Natural selection might account for the preservation and for the improvement of *adaptations*. It could hardly account for the differentiation of species through the development of characters that have no particular value to the organisms. Darwin was keenly aware of these facts, but he explained the seeming irrelevancy of the specific marks by assuming that variations in an organism are not confined to the trait which the observer discovers. What we see is correlated with obscure but important characters. It is conceivable, for example, that the increased hairiness of a part

is not of itself significant, but is a concomitant of an important but unnoticeable physiological quality. We may see no particular advantage in the pattern on the wings of a lady beetle, which we can distinguish only with the aid of a magnifying glass, but it is not difficult to believe that this pattern, insignificant though it may be in the struggle for existence, is merely an outward and visible sign of a significant property in one of the vital organs.

Selection and Protective Coloration

Among the striking examples which Darwin used to illustrate the probable workings of natural selection were colorations and patterns in animals. Protective coloration had been observed before, and had been accepted as part of nature's scheme (see pages 148 f). In more recent times the American artist, Abbot H. Thayer, made careful systematic studies on the visibility of birds and mammals under different conditions of illumination, and against different kinds of background. He showed very clearly that in many cases the distribution of pigment is definitely protective or concealing. Bars of white break up the outlines. The white bellies, on account of the shading of the under surface, produce a continuity of color-tone. Mottled surfaces and other conditions are unquestionably effective in making the individual indistinguishable in his natural settings. Darwin's theory raised a new question. Do those special colorings furnish animals effective and advantageous concealments in their everyday relations to their natural enemies and to their prey?

Cesnola attempted to find out whether the color was a factor in protecting green and brown mantids, insects related to grasshoppers and walking sticks. He exposed these animals against green and against brown backgrounds. He found that birds destroyed a larger proportion of the insects placed against a disharmonious background than of insects placed upon harmonious backgrounds. These results were

taken to show that the matching of the animal's color to the background is an important element in its protection. The closer the agreement in colors, the less likely is the animal to be destroyed.

Darwin himself in *The Origin of Species* says, " Hawks are guided by eyesight to their prey — so much so, that on parts of the Continent persons are warned not to keep white pigeons, these being the most liable to destruction.

In 1907 Dr. Charles B. Davenport reported from the Station for the Experimental Study of Evolution at Cold Spring Harbor that twenty-four chicks had been destroyed by hawks one afternoon, and that only one of these had a barred or mottled pattern. The inference which Davenport drew was the obvious advantage to the birds of a pattern that made them invisible to their enemies. Two years later Raymond Pearl at the Agricultural Experiment Station at Orono, Maine, reported on fowls destroyed on the range in the course of a season. Out of some 6600 animals, 325 were eliminated by rats or by other enemies. Of these 290 were barred and 35 solid color. The proportions destroyed in each group were almost identical. Pearl concludes, " The relative inconspicuousness of the barred color pattern afforded no great or striking protection against elimination by natural enemies during the season of April 1 to October 1, 1909 on the poultry range of the Maine Experiment Station." Whatever color pattern may do for birds elsewhere it cannot be assumed of equal protective value under all circumstances.

Protective Resemblance

Another type of protection was assumed by Darwin to come to animals that resemble others so closely as to be mistaken for them. According to the theory, the model is already protected by disagreeable taste or otherwise against its natural enemies. The mimic, by taking on this appearance, received a secondary protection. It was not supposed, of course, that any species of insects deliberately took on

the appearance of another species. Darwin explicitly repudiated the suggestion that there was any inward aspiration to the favorable mask. He supposed only that, in so far as individuals of one species do resemble another species already favored, they would stand a better chance to survive and leave progeny. With succeeding generations this increased resemblance to the protected species would accumulate until the existing conditions of mimicry had evolved.

As a matter of fact, it must be conceded that there are striking resemblances between butterflies of one family and butterflies of another family, and that even some flies resemble bees and wasps which belong to a totally different order. The argument, however, that these resemblances were developed in the course of natural selection takes altogether too much for granted. It assumes, first of all, that the model species is of itself protected by a disagreeable taste, or otherwise, so that it is relatively free from molestation by the natural enemies of the group. This protection, to be sure, is not automatic. It is necessary for the natural enemies in a given region (for example, birds or frogs) to discover each for himself that insects of a given appearance are to be avoided. We can watch young chicks pecking at "worms" and bugs, and learning in a few days to avoid certain creepy things and to feed exclusively upon others. Each generation of a species protected by disagreeable taste, for example, must sacrifice a considerable number in order to educate the enemy to take warning from the distinctive appearance. To be of protective value to the mimic, under such circumstances, it would be necessary that the model be much more numerous in a given area. Otherwise the mimic species would have to sacrifice a disproportionate number of individuals toward the education of the common enemy and would in fact neutralize excessively the education carried on by the distasteful model.

The theory assumes, in the second place, that the protective value of the resemblance would be acquired through natural selection in an area in which the model had already

established, so to say, a reputation for disagreeable taste. It has been impossible to decide whether, as a matter of historical fact, the mimics did actually arise in an area in which the model forms were prevalent. At the present time, however, we find that although two such "resembling" forms frequently occupy the same or overlapping areas, at other times they live in totally separate areas.

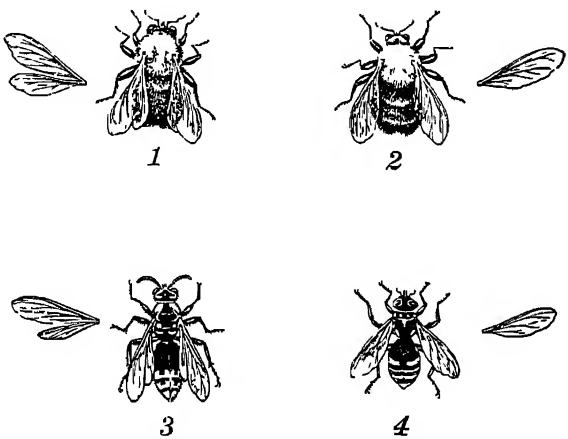


FIG 87. MIMICRY AMONG HOVER FLIES

A bumblebee (*Bombus pennsylvanicus*), *1*, is supposed to be "mimicked" by the hover fly (*Laphria thoracica*), *2* In the same way, the wasp (*Vespa maculata*), *3*, is imitated by the hover fly (*Spilomyia fusca*), *4* Striking cases of mimicry are found in all parts of the world, sometimes under circumstances that do not permit the usual interpretation of advantage to the mimic, or of some influence of the model in the development of the pattern From Gruenberg, Elementary Biology, published by Ginn & Company.

One remarkable example of the latter condition is furnished by the group of flies, the *Syrphidæ*, in southern Japan. Flies of this family are exceptionally numerous and are also remarkably similar in their general appearance and movements to certain insects that belong to the bee and wasp order (Fig. 87). Moreover, the flies hover about flowers and have in relation to the plants precisely the same effect as bees would have, that is, in the distribution of pollen.

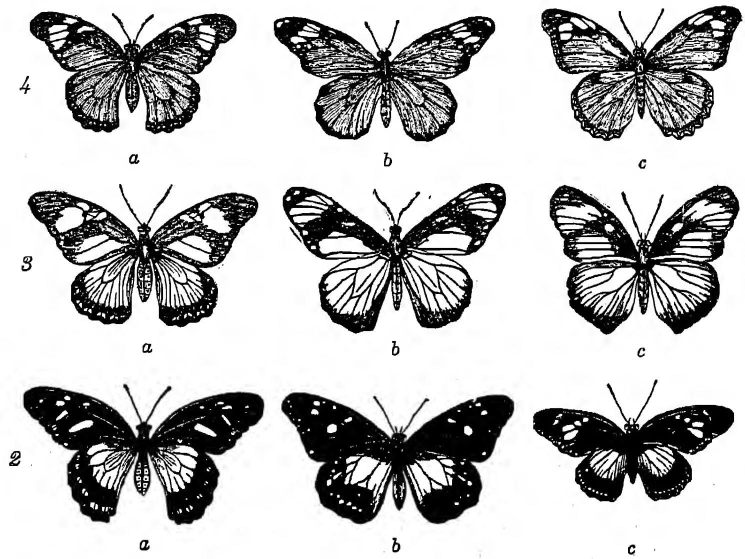
At the same time, bees and wasps are particularly scarce in this region, so that flies are deprived of whatever advantage they might theoretically derive from their resemblances to the stinging insects since there are not enough of the latter in the region to teach the birds to let them alone.

Chance Resemblances

Aside, however, from the speculative interpretation of natural resemblances, we have acquired more recently some definite information on the inheritance of color and pattern, particularly in insects. Among certain tropical butterflies, the male and the female have different patterns of wings. In one of these groups there are several distinct female types. One of the female forms resembles most closely the male of the species; but each of the others may be said to mimic two or three other species (Fig. 88). By means of breeding experiments, it has been shown that the pattern of wings in these animals is determined by several distinct factors, which are inherited in a definite way (page 274). The theory of mimicry as having developed through natural selection, because of the protective value, is plausible enough. It suffers, with the rest of the natural selection theory, in disregarding entirely the *sources* of those variations that make differential death rates possible. How does a particular appearance, color or form arise in the first place?

Many years ago the late Dr. Bashford Dean collected a large number of natural objects on which could be discerned more or less distinctly a figure suggesting a human skull. He elaborated from this material the absurdity of attributing to a particular pattern the adaptive advantage which Darwin's theory presumed. The death's-head pattern on a moth's wing or on the back of a crab may look sufficiently like a skull to frighten a human being who is frightened by such an image. To assume that this pattern is present on the wing of the moth because of a special advantage seems rather far-fetched. The same pattern is also to be

found on pebbles and on various plants and animals where it can not by any stretch of the imagination serve a useful function. The same, however, may be said of any particular



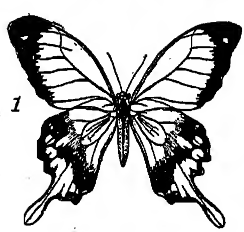


FIG. 88. MIMICRY OF THE AFRICAN SWALLOW-TAIL BUTTERFLY (*Papilio dardanus cenea*)

The male, *1*, is quite constant in appearance. The female, *a*, however, occurs in three distinct forms, and each of these bears a closer resemblance to butterflies of other genera than it does to its own male. Thus, the form *cenea*, *2a*, resembles *Amauris echeria*, *2b*, which in turn resembles *Pseudacraea tarquinia*, *2c*. The form *lippocoon*, *3a*, resembles *Amauris niavius*, *3b*, which in turn resembles *Euralia walbergi*, *3c*. The form *trophonius*, *4a*, resembles *Danais chrysippus*, *4b*, and this in turn resembles *Diadema misippus*, *4c*. The argument that these resemblances are of protective value seems plausible, but experimental studies point rather to the presence of numerous hereditary factors that bring about different patterns in the females. From Gruenberg, Elementary Biology, published by Ginn & Company.

pattern that we find in the wing of a butterfly or moth; and the same may be said if a similar pattern is found in an insect of a different family. In other words, there is no reason for assuming that every detail which we can observe is of necessary advantage, or has arisen because of natural selection.

Measuring Selection

During the nineties of the last century a breakwater was built near the mouth of the Plymouth River in England. At certain points in the sound the flow of the stream was slowed up, so that there was an increase in the amount of fine clay and mud settling in some regions. There followed an increased mortality among the crabs. Professor W. F. R. Weldon, a confirmed Darwinist, undertook to find what differences were to be observed between the crabs that were killed and those that survived. He made hundreds of measurements. The killed crabs were slightly broader than those that survived. This difference showed a consistent tendency. Moreover, as measurements were continued year after year, there was observed the tendency for the average width of the surviving crabs to diminish.

Similar measurements were repeated on crabs placed in an aquarium with fine clay in suspension. Dr. Weldon drew two conclusions from these studies. First, the average frontal breadth of the crabs was diminishing year after year at a measurable rate, which was more rapid in the males than in the females. Second, this diminution of the average frontal breadth was taking place in the presence of a material which was increasing in amount and which could be shown experimentally to destroy the broad crabs more rapidly than the narrow ones.

Francis Galton was the first to attempt the application of mathematics to biological problems. He had proposed the statistical comparison of groups of plants and animals in which selection could be observed. His methods were later extended by Karl Pearson, under whose leadership many such studies were carried on. Pearson collected measurements over long periods of time, for many species and for many characters. He compared the mean magnitude of characteristics in organisms that died with the corresponding measurements of those that had survived. He compared the measurements of a given trait in the whole population

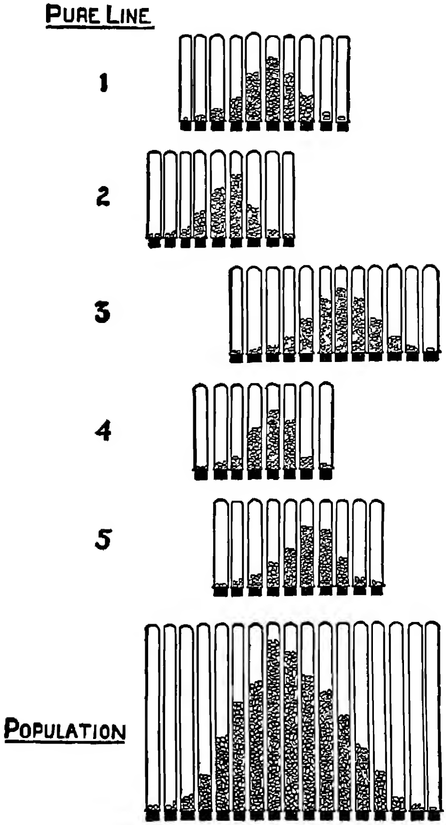


FIG. 89. JOHANNSEN'S PURE LINES

By intensive inbreeding of self-pollinating beans, Johannsen established some nineteen *pure lines*, all derived from a mixed population A large seed and a small seed from one such pure line would yield identical progenies — that is, groups having the same mode and the same range of variation. Another pure line shows a different mode and a different range, but overlapping the range of variation of the first It is possible, therefore, to find a bean from each one of the lines 1, 2, 3, 4, and so on, that all *appear* to be alike (phenotypes), and yet to obtain from each of these similar seeds a distinct progeny (genotypes) On being thrown together the seeds of these several pure lines form a population presenting a continuous series, *as if* they were all members of the "same species" After Johannsen

and in the survivors. In this way he hoped to find a mathematical index of the effectiveness of natural selection. A great deal of material was thus accumulated in support of Darwin's theory.

Later, however, more critical studies along the same lines threw some doubt on the interpretations of the facts. We have already seen (page 179) that Villem Johannsen, the Danish botanist, experimented with self-pollinating beans, and showed that selection has no effect whatever in modifying the constitution of the variety. Johannsen succeeded in breaking up a mixed population of beans into several distinct strains or pure lines. Then he showed that although there is individual variation within each pure line, the strain has its own mode and its own limits of variation (Fig. 89).

The net result of these experiments was to show that it is possible by means of systematic selection to establish a strain having a mode or average quality differing from that of the ancestors, but *it is only the average that is shifted, not the essential characteristics of the population.* It is possible, for example, by means of selection to obtain a group of larger animals or of smaller animals and to maintain the extreme size consistently in successive generations; but it is not possible by this process to transcend the original limits of variation of the parental type. Selection, in other words, acts upon the average of a mixed population, but does not affect the genotype of a pure line. This is in agreement with the well known experience of breeders that improvement results very rapidly from consistent selection for a few generations, and then stops almost abruptly. There is a point beyond which selection does not carry improvement further.

What is Selected

Darwin assumed, from the well known results of artificial selection, that not only does the mean or average

quality of the race move in the direction selected, but that *the range of variation would also move in the same direction* in each successive generation (see Fig. 90). Galton had already shown from his measurements that this does not take

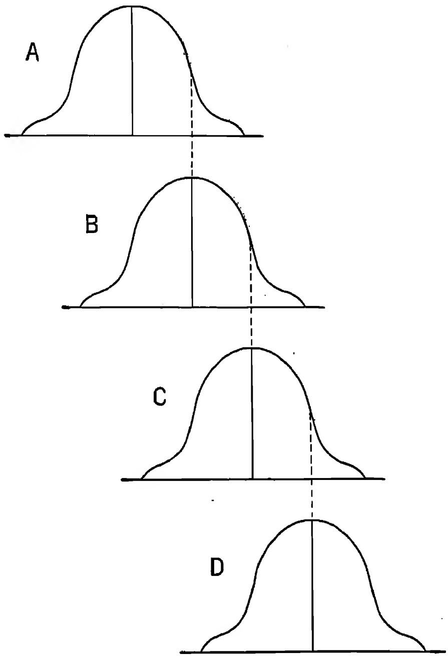


FIG. 90. DARWIN'S ASSUMPTION

The theory of natural selection, supported in part by experience with artificial selection, assumes that if from a mixed population, A, individuals are selected near one extreme of the range of variations, these will give rise to a group, B, that fluctuates about a new mean corresponding to the character of the selected parents. If the process is repeated, the mode and the range in the following generation, C, will have shifted still further in the direction of the selection, and so on indefinitely. After a number of generations, the descendants, D, of the original population will present characteristics definitely beyond the ancestral range of fluctuations. Pure-line experiments in breeding have not supported this view.

place (Fig. 91). So thoroughly, however, had the Darwinian mode of thinking become assimilated among the biologists, especially in England, that for many years Johannsen's work made no impression whatever. It was impossible for Darwinists to see the implications of these studies.

Jennings in this country had cultivated paramecium through many generations and obtained results similar to those of Johannsen with beans (Fig. 92). In later experi-

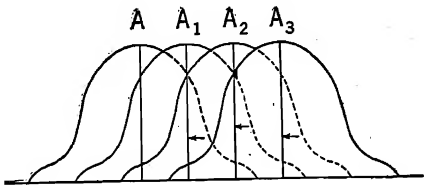


FIG. 91. GALTON'S LAW OF FILIAL REGRESSION

The sons of tall fathers will be taller than the population in general, but not as tall, on the average, as the tall fathers. There is a tendency for the offspring of deviates to approach the general run of the population. If from a general population, A, extremes are selected as the parents of the next generation, A_1, the new generation will have a mode and a range different from the previous generation, in the direction of the selection; but the mode will not correspond to the characters of the selected parent. Similarly in successive generations, A_2, A_3, and so on. The regression is represented by the length of the arrow — that is, the distance between the selected parent and the actual mode of the following generation.

ments, however, Jennings obtained different results in another one-celled animal, *Difflugia,* which may be likened to an ameba with a sandy outer shell (see Fig. 17). Careful selection yielded several distinct strains recognizable by the character of the shell, the number of protuberances, and the appearance of the mouth of the shell.

Dr. W. E. Castle also produced a noteworthy differentiation of type by means of selection (Figs. 93 and 94). This was apparently a clear case of establishing a character

Portrait loaned by Dr G H. Shull

WILHELM LUDWIG JOHANNSEN

DENMARK 1857–1927

by selecting in the direction of the extreme. Later studies, however, raised many doubts as to just what was accomplished by the selection. There is no doubt about the final appearance of the animals. There is no doubt as to pheno-

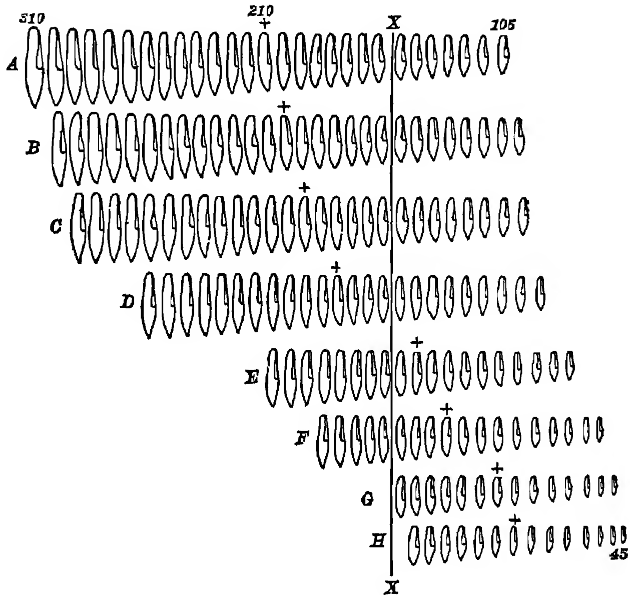


Fig. 92. Pure Lines in Paramecium

In these one-celled animals reproduction is by cell division By following up the descendants of a single cell it is found that although in each generation the progeny varies in size, the descendants of a large individual furnish the same kind of population as the descendants of a small individual. Each row represents one such pure line, + marking the mode There is a great deal of overlapping, so that in a mixed population of several such pure lines the distribution about the mode, *X*, suggests the continuous variation found in a single strain Selection from such a mixed population may isolate several genotypes, but apparently does not change the species After Jennings

types in the successive generations. The doubt is raised by Morgan and others as to just *what happens in the hereditary mechanism.*

We have already seen that pigmentation and coat pattern may be determined by many factors. Some of these factors act as modifiers, some diluting, some intensify the

FIG. 93. ARTIFICIAL SELECTION OF HOODED RATS

Beginning with hooded rats which he had obtained in the course of an experimental study of the heredity of coat characters, Castle selected one series with a very narrow black stripe along the back in the direction of less and less color, and another series in the direction of more color After several generations, he obtained two extreme types a white animal with pigment confined to the head and shoulders, and a black animal with white confined to the belly Photographs through the courtesy of Professor W E Castle

pigment; some make for continuity and some for the breaking up of the pattern, and so on. After segregation, the progeny of hybrids include many types. In an experimental animal selected from such a group, the particular appearance is due to the presence of specific factors related to the pigment and pattern. But there are present also many factors lying latent, and still others that merely modify the outward manifestation of the inherent capacity. Selection is carried on with the attention fixed upon the outward pattern.

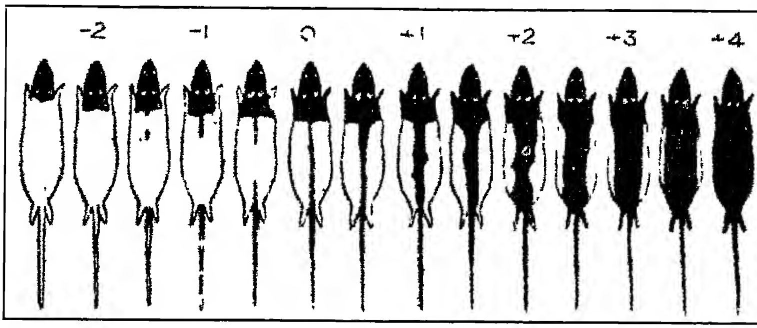


FIG 94 VARIATION OF PIGMENTATION IN HOODED RATS

This is a scale for measuring coat-patterns in experiments designed to produce extreme types by artificial selection, beginning with the type O and working in opposite directions After Castle

The experimenter or breeder must inevitably carry through the successive generations heritable factors of which he does not know but which nevertheless influence the final results. When the extreme types have appeared they are composites of numerous hereditary components. Successive breeding over many generations is necessary to disentangle the complex. This is the argument which the geneticists have opposed to the assumption that such results as Castle obtained represent a simple cumulative effect of selection.

The students of genetics have already shown (1) that a change in a gene involves as a rule alterations in several organs and not merely in the one upon which the experi-

menter has fixed his attention; (2) that a change in a given organ may be brought about by alterations in any one of two or more genes. It is therefore in accord with the known facts to assume that selecting for a particular trait may carry in its wake far-reaching alterations in other traits. It is also in agreement with the known facts to suppose that systematic selection results in segregating factors which will determine the appearance of distinct traits in successive generations. It remains certain at any rate (1) that the most reliable experimental selection has never resulted in transcending the normal range of variation of the parental type, and (2) that the apparent establishment of new types through systematic selection can be explained on the theory of factorial determination of characters.

Darwin's Own Misgivings

Darwin never claimed quite so much for the doctrine of natural selection as did many of his enthusiastic followers. Certainly he did not claim for natural selection that it was the exclusive means by which species are modified, but only that it was the most important. Certain types of problems troubled him particularly although he remained confident that a more thorough study of the facts would support his theory.

The first of these difficulties was the consideration that *if* natural selection were actually taking place, it should lead to the presence of indefinite intergrading forms instead of to definite fixed species. The accumulation of knowledge shows (1) that there are actually more intergrading indefinite forms than Darwin suspected; and (2) that there are many species that are far from fixed.

Darwin saw a second difficulty in the development of trivial, relatively insignificant organs, such as a tail, as well as highly complex structures, such as the vertebrate eye. It was difficult in the latter case to conceive what competitive advantage would come from the rudiments of

an eye incapable of seeing, and yet serving as a basis for progressive improvement. Unless an animal could use such an organ, it would have no advantage over others without even a beginning. Darwin felt, however, that the evolution of the eye from a rudimentary pigment spot sensitive merely to varying intensities of illumination could come about through natural selection by the accumulation of advantages, given sufficient time.

Another serious problem is the development of very complex instincts, especially in the higher branches of the different phyla. The social insects, for example, perform most intricate acts that are definitely related to the survival of the individual and of the species. These could not by any conceivable means have been acquired in their entirety at any one time, and yet could not be of survival value unless they were effective in their entirety. Here too, Darwin thought, diligent search for intermediate stages might show that instincts had evolved from the simpler to the more complex by small stages at each of which natural selection could have been effective.

Finally the problem of intersterility of species was a source of a great deal of concern. Although sterility is frequently found among varieties of the same species, it is much more common when different species are crossed; and the offspring of specific crosses are themselves often sterile. Since there was no definite knowledge regarding the mechanism of reproduction and heredity in Darwin's time, it was possible to account for the sterility only by saying that there is some disharmony between the reproductive mechanisms of the two species. We do not know very much more today. But we do know that in some cases the important factor lies in a difference of chromosome numbers; and that in other cases the chromosomes are so distinct in two species that there cannot be the normal coupling which takes place after fertilization. The utmost that Darwin's natural selection could furnish toward the solution of this problem is the suggestion that as a type diverges from the parental pattern

there appear correlated divergences in the reproductive mechanism.

This raises the question whether selection itself brings about changes in the constitution, something that Darwin himself was inclined to doubt.

The Origin of Fitness

We note that there are many varieties of seed structures and that the shape of some seeds fits them to be scattered by the wind. We assume, therefore, that the advantage which comes to the species from having its seeds widely scattered is in some way a *cause* of the seeds having the shape in question. It would be just as logical, however, to say that many seeds having shapes or appendages of certain kinds are scattered by the wind. If these plants had seeds of a different shape they would be scattered by moving animals or by migratory birds — as is indeed the case with some species.

Darwin pointed out that in the domestic duck the bones of the wing weigh less, and the bones of the leg more, in proportion to the body skeleton, than do the corresponding bones in the wild duck. This change from the ancestral condition may be safely attributed, he thought, to the fact that the domestic duck flies much less and walks more than did the wild ancestors. Accepting the facts as stated, however, would it not be as logical to say that the domestic ducks with reduced wings fly less because their wings are inadequate, as to say that they have reduced their wings because of their flightless mode of life?

Neither Darwin nor Lamarck nor any other naturalist pretends to know how a particular variation arose in the first instance. It is a matter of common observation that homologous organs in a series of animals are actually adapted to the varying conditions under which the several species live. To say, however, that such organs are modified to suit the conditions of life is to imply that the conditions were effective

causes in bringing about the modifications, whether in the Lamarckian sense or in the Darwinian sense. It may be worth while to consider the alternative possibility. It is just as true to say, for example, that the diverging types of animals live in a manner and in habitats to which they are adapted by the special or peculiar forms, connections, sizes, locations of their various organs.

Neither Lamarck nor Darwin attempted to account for the origin of fit variations nor for the adaptiveness of the individual to changed conditions. Darwin assumed merely that some of the many variations possible would be more valuable than others. And Lamarck assumed as an ultimate fact the tendency of living things to respond suitably to the environment. At the present time, we have to accept adaptiveness as an ultimate character of living matter.

General Objections to Natural Selection

If existing forms of plants and animals have come about as a result of natural selection acting through untold ages, there ought to be greater stability or constancy in living things rather than variability.

The doctrine of natural selection does not account for the reduction of unused organs, for the degeneration of the eyes of cave animals, and so on. Species differ from each other in more than one detail, and the theory would require the *simultaneous appearance* of numerous variations and their *joint preservation* by heredity after the action of natural selection. The struggle for existence which leads to the survival of one set of characters in a given situation would leave others to be swamped by the interbreeding of unselected individuals. It is difficult further to understand the appearance of *correlated variations* which are necessary for the effectiveness of special organs, especially in higher animals. For example, a stronger muscle to be of value must have correspondingly larger areas of attachment on the bones; and a stronger muscle might be a source of harm if

the bones were not correspondingly stronger. The organism acts as a unit and specializations in one part of the body can be of advantage only in the presence of related specializations in other parts.

The theory of the struggle for existence has implied too severe a contest with respect to most species and particularly in relation to detail of structure or function. It is true that at any given time only a small fraction of the progeny of a given species will survive, but the extermination is not generally of a kind that will insure a differential survival of "superior" individuals. Many organisms have structures and instincts that are actually injurious to them, yet these do not lead to their extermination. It is sufficient only that the injuries are not fatal. The flight of the moth to the candle will destroy annually many millions of moths, but not enough to destroy the species having this instinct. Many plants and animals are able to survive in spite of obvious handicaps.

Isolation

The appearance of a favorable variation, aside from the question of selection, can serve as the beginning of a new variety only (1) if the quality in question is transmissible, and (2) if the individual or individuals bearing the new character are protected from swamping by the vast number of conformists. Many suggestions have been made to meet this difficulty. Moritz Wagner considered an essential part of the theory of natural selection the fact of *isolation*. This makes it possible for the varying individuals to reproduce their distinctive traits unaffected by the regressive effect of the large numbers of the parental type. It has been shown in fact that the differentiation of types does actually take place wherever there is isolation. The studies of Gulick and Crampton on snails (see page 190) furnish an excellent example. Darwin himself had accumulated numerous examples of rabbits, dogs, cattle, and other animals, develop-

ing distinct types in a segregated area. Regional varieties or species of birds, mammals and other classes of animals are well known to taxonomists (Fig. 41). David Starr Jordan, who had himself recorded observations on regional types, especially among fish, constantly stressed the importance of barriers to the swamping or merging of variants. He observed moreover the tendency of variation to produce distinctive lines under isolation: "As dialects form in human speech, where men cease to mingle generally, so species form among animals or plants where there exists a check to migration."

Another suggestion to meet this difficulty is the theory of physiological isolation. If two or a few individuals show a distinct trait this particular quality can be preserved in future generations only if those having the character mate together and avoid mating with the mass of individuals not showing the trait. We have since found, however, that if a particular character appears in a heritable form in a single individual, it would be possible for it to reappear in subsequent generations, and eventually to become established, even though the mate of the first variant did not show the same trait. A strain of wheat was discovered in England to be immune to rust. This quality was found to be a Mendelian recessive. By crossing this immune wheat with other varieties, it is possible to combine the quality in question with other desirable traits in a new strain.

Isolation as a factor in evolution may be considered important regardless of whether natural selection itself proves to be as effective as Darwin considered it. In many observations on the development of human qualities in races, tribes, or sects, isolation plays an important rôle. Eugenists, who are for the most part disposed to follow the Darwinian interpretation of the evolutionary process, stress the persistence of distinct groups of traits in segregated human stocks, such as the famous Jukes family, the Parsees of India, the Icelanders. They fail, however, as a rule, to distinguish clearly between the hereditary factors that repeat them-

selves in successive generations and the effect of a virtual isolation. There is no doubt that a social or religious process which virtually confines a group of people to restricted mating or inbreeding will tend to preserve hereditary traits that would otherwise become diffused in the larger population, and to intensify recessive traits that would otherwise be masked by their dominant alternatives. Beyond that, however, it has been difficult, in considering the evolution of human qualities, to separate with certainty organic traits that are truly inherited from the effects of social processes.

Proving Too Much

One of the standard illustrations of a highly specialized adaptation used to show how natural selection could bring about a distinct type is that of the kallima butterfly (see Fig. 95). According to the theory of natural selection, the resemblance of this insect to a dead leaf is of protective value. This pattern is the result, according to the theory, of accumulation through many generations of progressively closer resemblances to the dry leaf. It is assumed that some remote ancestors of this species included among their number some that resemble a dry leaf only slightly and that these survived in competition with their fellows who looked less like a dry leaf. It is assumed further that in succeeding generations the progeny contained a larger proportion of individuals resembling the dry leaf and that this resemblance increased from generation to generation. Suppose we grant, for the sake of the argument, that this process of natural selection and transmission of favorable variations continues. We may then conceive that a point is reached at which the resemblances of the ordinary individual of the species to a dead leaf is sufficient to secure complete protection. An examination of the existing kallima, however, shows us an over-refinement of the resemblance for which the theory of natural selection offers no explanation.

FIG. 95. THE DEAD LEAF BUTTERFLY

The brightly colored upper surfaces of the wings of the *Kallima* butterfly of India make the animal conspicuous while in flight. When the insect is at rest, however, the under surfaces are exposed and present a striking resemblance to a dried brown leaf It seems common sense to suppose that when in this position the insect is likely to be taken for a leaf by possible enemies, and so left unmolested Observations in the field, however, would indicate that both birds and lizards prey upon the insect in spite of its "protective" appearance.

In addition to the general form and markings that suggest a midrib and principal veins, we find a spot that looks for all the world like a hole made by a fungus or an insect eating through the leaf. It strains the imagination to assume that this finishing touch to the protective pattern had

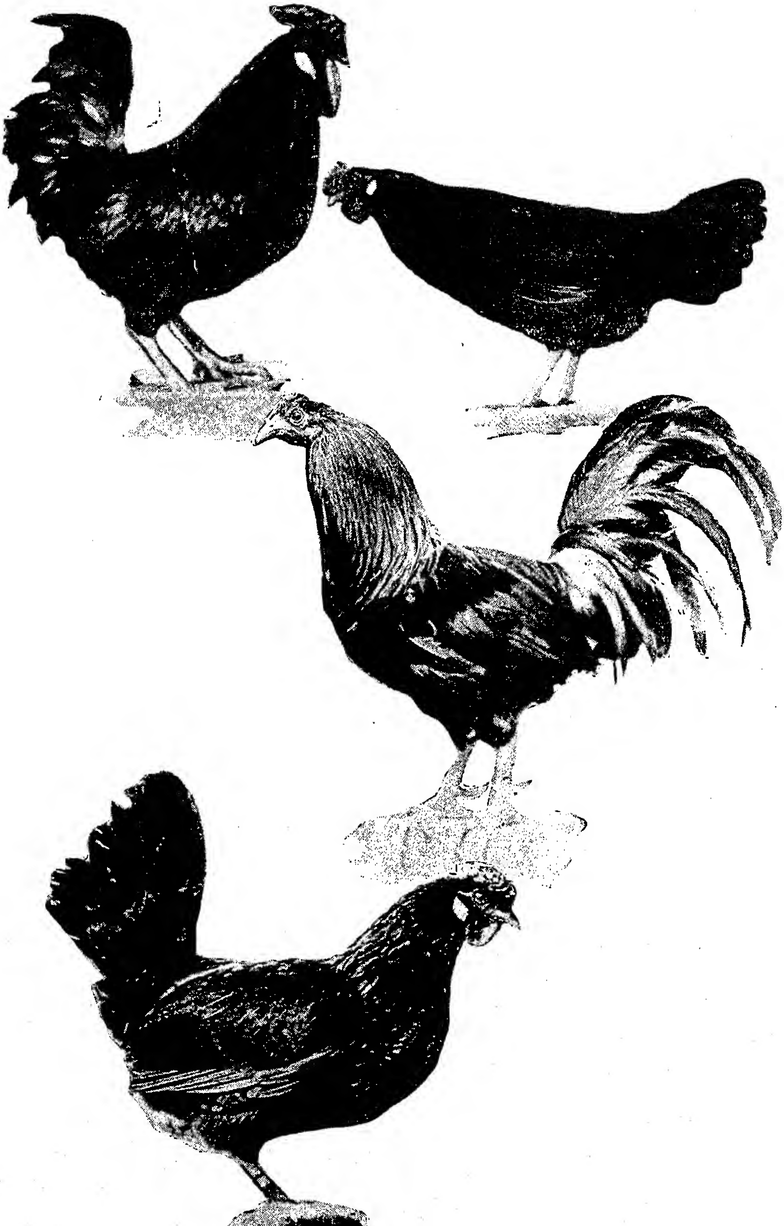
so much additional value that the individuals possessing it survived to the exclusion of the kallimas who looked like dead leaves without this stigma of decay.

We can see, granting the premises, how natural selection would lead to stronger and sharper weapons of offense and defense. But we cannot see how this same process would lead to the development of tusks of such form and magnitude that they would interfere with the possessor's use of them, or to the development of horns that were too heavy for the animal's muscles to manage Other examples of overspecialization are to be found both among existing forms and among those that have become extinct (see page 189). Whatever a given structure, pattern, or behavior may contribute to the survival of a species, we cannot assume it to increase in value past a certain point. In fact, the indications are that such overspecialization is injurious to the species. There is a point beyond which good things cease to be of virtue.

Sexual Selection

Among many animals, especially birds and mammals and some insects and other arthropods, there is a constant difference between the two sexes in body form and in special organs. The song of the bird, the mane of the lion, the horns of the deer are familiar examples of these secondary sexual characters confined to the male.

Recent experimental studies have connected the development of many such structures and characters with the internal secretion of gonads (the ovaries and the spermaries). A castrated male will fail to develop the distinctive characters of his sex. If a spayed female has implanted in the body the spermary from the male of the same species, the female will develop some of the characteristics of the male. These facts had not been so clearly perceived in Darwin's time; and the theory of natural selection had to explain these sex differences (see opposite page).



INTERNAL SECRETIONS AND SECONDARY CHARACTERS

The normal male and the normal female of the Brown Leghorns (top) are unlike in certain characters. The capon (middle), a male bird from which the testes have been removed early in life, has some of the characteristics of the male, but lacks others, particularly the large comb and wattles. If the testes are removed from a male bird and the ovary of a female is then engrafted into the body, the maturing bird develops certain traits that are definitely feminine (bottom). Photographs through courtesy of Dr. H. D. Goodale.

The theory of sexual selection was developed for this purpose. From Darwin's point of view, sexual selection meant the effect produced by the preference which the female of the species exercised in the choice of her mate. The beautiful plumage or song of the male bird would have a competitive value and the superior males would alone have the opportunity to leave offspring. Among these, in turn, the males would show the desirable qualities in an enhanced degree. This theory assumes an æsthetic discrimination on the part of birds, mammals, insects, etc., which it is difficult to establish. It assumes further that the selection is so severe that only the few superior males would have an opportunity to leave progeny.

With respect to certain moths, Fabre and others have shown that the difference between the male and the female wing pattern plays no part whatever in reproduction. The male finds the female through the sense of smell and the two sexes are unmindful of the wing patterns, whether in the light or in the dark. Where the wings of the male were attached to the female, or *vice versa,* the behavior of the animals remained unaffected.

Wallace interpreted sexual selection in a somewhat different way. In the case of the birds at least, he noted that it is the female that usually sits on the eggs and would be exposed to danger if she were too conspicuous in her coloring, or attracted too much attention through her song.

It is undoubtedly true that the peacock's tail and the nightingale's song play a part in the courtship of these animals. The male walrus or stag is more of a fighter than the female of the species, and the competition for females will give a stronger or more belligerent male the advantage. In this sense there is a selection since only the more effective males will leave progeny. Generally speaking, however, the facts to be observed among animals of many orders do not support the idea that sex differences have arisen or have developed because of the kind of advantage which is implied by the theory of sexual selection. This theory as a

general agency in bringing about sex differentiation is not considered seriously by most naturalists.

Summary

No matter how variations arise, no matter how they are inherited, no matter how severe or how mild the struggle for existence may be, organisms can continue to live only if and only in so far as they meet the conditions imposed by the environment. Natural selection thus remains from the common sense point of view a permanent factor in determining survivals and in insuring that the species which do actually exist at any time shall be more or less fit. Indeed, so axiomatic is this that the question may reasonably be asked whether it tells us anything at all that will help us to solve the problem of evolution. We know that living things have among other characteristics the ability to adjust themselves more or less adequately. Each species is adapted to live in a relatively restricted type of environment. Does the doctrine of natural selection tell us anything more than that? Perhaps it is not always the fittest, or only the fittest, that survive; but obviously the unfit cannot carry on.

Natural selection cannot originate anything if it is, as defined, a truly negative agency, a destruction of the unfit. This process has been compared to the action of a mighty sieve which lets pass all below a certain standard and retains only those that meet a certain minimum requirement. The variations which appear in every array of individuals tend indefinitely in all directions, according to Darwin. There does not appear among them anything determinate, anything pointing definitely in a specific direction. There is a vague tryout of novelties without predisposition, without prejudice. And some of the trials happen to be lucky. The whole process is one of trial and error.

In describing this process as one of chance variations, Darwin did not of course intimate that variations were without cause. On the contrary, this " chance " characteristic is

due to the impinging upon each organism of a multitude of influences. Darwin meant to avoid any commitment as to an ulterior purpose as guiding the variations, and so the course of evolution. He sought to avoid the mysticism of an innate "principle" or tendency to vary.

Darwin's theory leaves us with the necessity for a further study of variations. We have to find out why there is variability both of heritable and of non-heritable qualities. We have also to find out in detail just what the mechanism is that results in heritable variations (mutations) of an adaptive kind. If the theory of natural selection may be taken to account for adaptation, it fails to tell us anything about how modifications arose in the course of descent. On the other hand, whatever knowledge we have about the sources of variations tells us nothing about the origin of adaptations. It is probable that further speculation, taking into consideration newly established facts, will have to include both Lamarck's emphasis upon the adjustability of the individual and Darwin's emphasis upon the elimination of the unfit.

With all the criticisms of the special theory of natural selection, there is a growing appreciation of Darwin's contribution in making the general theory of transformation a commonplace among all scientists and indeed all thinkers. If many of us often say "evolution" when we mean "natural selection" or if we sometimes think that the latter is as well established a "fact" as is the former; it is because the evolution of human thinking has not yet gone far enough. Darwin has at least made it possible for more and more persons to consider the entire question of organic evolution from a fresh start. The inclusion of man among the living forms that have undergone modification along with descent from their ancestors has become something to think about without fear and without reproach. That is to say, more and more of us can accept the notion of human evolution from a more primitive type, even if leading anthropologists cannot agree on the hypothetical reconstruction from fossil

remains that should be honored as the common ancestor of man and the anthropoid apes.

Professor J. Arthur Thomson of Aberdeen says, "From a modal interpretation, organic evolution has advanced to the rank of a causal theory, the most convincing part of which men will never cease to call Darwinism." But never is a long time, and if evolution is a living process today, we may discover tomorrow a still more convincing part of a causal theory.

Chapter 12

Evolution by Jumps

NEW plants and animals with qualities especially selected to meet our purposes have become commonplace. We have different grains for different soils and different climates, as well as for different proportions of starch and protein. We have sheep for particular qualities of wool and sheep for the most economical production of mutton. We have cows for quantity production and cows for high butter yield; and studies now in progress promise for the near future a new type of cow that will combine the high yield of the Hereford type with the high butter fat of the Jersey type. These practical results are the living proofs of the biological theories regarding the process of evolution, of constant modification of the world's inhabitants. They are the living evidences of the effectiveness of certain kinds of "selection." In every case the breeder had to start with something given — a departure from the conventional structures and functional mode of the race, a variation. But variations are always present. Are they always available for the establishment of new strains or races — new species?

We have seen that the facts force us to make a distinction between fluctuating variations which result from slight variations in the conditions of growth and development — the phenotypes of Johannsen — and those other variations which seem to arise from more deep-seated sources in the germinal substance of the race — genotypes.

The Paradox of Change

With Darwin and his predecessors this was not an important distinction. Heredity used to be considered a "force" that somehow made the offspring resemble their parents, more or less, not a process for which we could expect to find the causal mechanism, at least not in the near future. We have seen that August Weismann made the distinction between characters that are heritable, because they are determined by something in the germ plasm, and those that are not heritable, because they appear in the body under the influence of environmental conditions (page 310). Weismann went farther and declared that those departures from the parental type which had their *origin* in the germinal material, are transmitted, whereas those variations from the norm which had their origin in the body or soma plasm are not inherited. He did not pretend to know *how* germinal changes come about, although he speculated and theorized profoundly on the problem. Indeed, his distinction between the germ plasm and the soma was largely a theoretical one, and we did not know until many years later that Weismann had hit upon an essential point.

It is difficult to imagine how new characters can originate in germinal changes. The same difficulty is presented by the general question of transformation of species, namely, the paradox of discontinuity. If the germ plasm has been continuous and unchanged for generations, if it has been the very foundation of stability for a species, in spite of fluctuating conditions and in spite of modifications impressed upon the bodies of millions of individuals, how can it suddenly acquire anything new? Weismann himself insisted most vehemently that nothing could happen to the germ plasm. Yet something must have happened to it (according to the theory) if evolution is to take place.

The opponent of the evolution idea cannot conceive how parents of one species can give rise to an individual that is of a different species. The evolutionist cannot conceive

how a new heritable trait can suddenly appear in a healthy stream of protoplasm. And yet something in the way of discontinuity is implied by the general theory of evolution, and by the facts. The paradox is similar to that propounded by the Greek skeptic Zeno: Motion is impossible because a thing cannot move where it is, for so long as it is there it is at rest; and it cannot move where it isn't, for it isn't there to do anything. And yet we know that things do move.

It is commonly assumed by many that the idea of evolution corresponds rather to a continuity of events and processes. The suggestion of discontinuity to explain evolution therefore appears self-contradictory. There is, however, no fundamental inconsistency. The continuous pressure of water in a pipe can furnish a continuous flow at the open end, under ordinary conditions. If the opening is closed down sufficiently, however, but not too much, we can get from the same continuous pressure a series of interrupted discharges — as in the case of a dripping faucet. This is only to say that a continuous force can be converted into a periodic or interrupted phenomenon. There is no intention of suggesting how discontinuity arises in protoplasmic heredity.

Natura Non Facit Saltum

Long before Weismann's time it was recognized among biologists that the facts which point to an evolution of plant and animal forms point also to some break in the continuity of heredity and generation. Huxley himself was a stout defender of Darwinism and a tireless promoter of the doctrine of evolution, yet in his review of *The Origin of Species,* shortly after the book came out, he noted that Darwin might have made out a stronger case for evolution if he had not committed himself to the maxim, *Natura non facit saltum* — Nature makes no jumps. Francis Galton, in his work on *Natural Inheritance,* saw no need for insisting upon the steps in evolution being *too* small. He saw the difficulty that if each step were very small, a new character would be of no

advantage except after many accumulations of small steps. Of course Darwin insisted upon the small, almost imperceptible steps, because this seemed to avoid the metaphysical difficulty. If the steps are small enough, they come within our everyday experience and do not need to be accounted for as something distinct from the facts of life in general.

The first definite criticism of Darwin's theory from this point of view seems to have been made, in 1864, by the zoologist Albrecht von Kolliker, who gave to the process of variable heredity the name *heterogenesis* — that is, the creation or birth of something that differed from the parents. This process, in theory, was compared to the formation of different molecules of chemical substances by the change of one or more atoms. It was assumed that each species was as distinct from others as is one chemical substance from another. Sodium sulfate differs from sodium bisulfate, for example, in that one atom of sodium in a molecule of the former has been replaced by an atom of hydrogen. There are no intermediate substances. In the same way there are no strictly intermediate forms between one species and the next, but there is a distinct jump from one to the next. It was necessary, according to this idea, to redefine species so that forms which are alike in most characters but differ in only one or two minor points are to be considered true species, or, as they were sometimes called, "elementary species." Kölliker conceived evolution to come about, then, by heterogenesis, or the appearance of forms that were at the same time distinct from their parents and yet capable of passing on their own distinct traits to their offspring.

Stability with Change

The word *stability* suggests something anchored firmly in the rock bottom of the universe, or at least of the world. But that conception is relative, in the sense that there may be many degrees of stability. And it is compatible with change or movement. The earth, for example, is stable. We do

not feel either its wobbling or its movement. Yet we have good reason to believe that it is moving at a rate that staggers the imagination, and that its flight through space is not absolutely smooth. The germ plasm is also stable, compared to the developing protoplasm of an individual plant or animal. Yet this stability is compatible with the kind of change which the idea of evolution presupposes.

Francis Galton developed this thought by using a simile from geometry. A material body may be in such stable equilibrium that although it yields considerably to pressure from various directions by rocking on its base it always re-

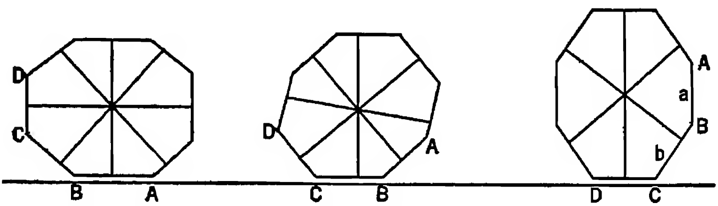


FIG. 96. GALTON'S PRINCIPLE OF PRIMARY AND SECONDARY STABILITY

A polygonal block that is not symmetrical can be made to stand on any one of its faces, on a level surface It is more stable in some positions than in others, however. Similarly a natural species may fluctuate considerably about a mean and yet remain fixed, or it may transcend the normal range and jump into a new, more or less stable, position See text After Galton

turns to its normal position (on A–B in Fig. 96). A push above the ordinary, however, would shove it into a new position. This corresponds to a sub-species; and here it could maintain itself, subject to minor disturbances (on C–B in the figure). A second violent disturbance might push the block into its original position, or into a third position corresponding to a new type (on D–C in Fig. 96). In this way a species may be conceived to endure a considerable range of fluctuating variation and yet remain always essentially the same species. A change in hereditary constitution would make the fluctuations transcend those of the original condition, and would shift the whole of succeeding generations into

a new state of equilibrium around a new mode. In some such way as this, thought Galton, we can conceive of evolution as a process of shifting the equilibrium or mode of a species, and we could account at the same time for

"(1) variability within narrow limits without prejudice to the purity of the breed;

(2) partly stable sub-types;

(3) the tendency, when much disturbed, to revert from a sub-type to an earlier form; and

(4) the occasional sports which may give rise to new types."

As a purely abstract description of the facts, Galton's model may serve to reconcile the contradictory behavior of living things, especially the paradox of permanence and stability going hand in hand with perpetual change. This is helpful, although it gives us no hint whatever as to just what it is that happens in living substance to bring about the observed results.

Continuous and Discontinuous Variation

It became increasingly difficult to reconcile the Darwinian explanation of evolution, natural selection, with the assumption of progressive accumulation of imperceptible variations. It finally became necessary to reëxamine the fundamental facts. As a beginning of this task William Bateson assembled a large mass of data, *Materials for the Study of Evolution,* in which are given hundreds of cases of discontinuous variations — that is, variations that transcend the normal fluctuations found in every species.

The best material is found among traits in which the specific character is represented by a numerical constancy — for example, the number of digits on the hand or foot, the number of ribs or vertebræ, the number of petals or carpels in a flower, the number of joints in a leg or a finger (see Fig. 55). In such characters it is obviously impossible to

have a series of intergrading forms. There are either twelve ribs or there are more, or fewer; the cow has horns or she has not. Each numerical value stands distinct from the next. Stature or any other dimension might fluctuate by "imperceptible" degrees. Physiological characters may fluctuate more or less. Things that we can count, however, are always in a *discontinuous* series. Many of the cases are undoubtedly monstrosities or morbid conditions, such as the growing together of parts that are normally separate, or the development of supernumerary legs in a calf. Many others, however, represent discontinuities that cannot be considered "freaks" or monsters.

Studies made among many species of plants and animals showed these discontinuous numerical or meristic variations to be very common; and in many cases the variation from the normal was found to be transmitted to offspring — the broad-fingered condition in man, for example, wherein the fingers are found to lack one joint (see Fig. 56).

Another type of discontinuous variation illustrated in Bateson's collection is represented by the transformation of an organ into another homologous one. Among flowers, for example, leaflike structures sometimes appear in place of the stamens or carpels, as in the formation of "double" roses. Among crabs one sometimes finds an eye replaced by an antenna. Skin glands sometimes take on the structure of milk glands. Many other abnormalities are reported, indicating the development of a specialized organ into one less specialized — and sometimes a divergence in the opposite direction.

The Origin of the New

At the end of the Nineteenth Century the discussion among the evolutionists centered around the evidence for

(1) the *origin of variations* that might serve as the basis for selection; and around the evidence for

(2) the *effectiveness of natural selection.*

Theoretical objections to the idea of evolution by natural selection of the minute fluctuating variations continued to accumulate. The Russian naturalist Sergius Korchinsky objected to the idea of the struggle for existence as part of the evolution concept because adverse conditions of life, he thought, would tend to stabilize forms and prevent the appearance of new departures, thus hindering evolution. In society, when conditions of life are difficult and when competition is severe, there is no opportunity for the establishment of new ideas. There is no chance at all for the unconventional.

We do not know how far Korchinsky was influenced in his views of the struggle for existence by his own social theories and by his revolt against the political and economic complacency of the Russian aristocracy. It is interesting, however, to find that Luther Burbank, less given to speculation and with a radically different background, came to similar conclusions, although to entirely different applications. Burbank sought for desirable variations only where his trial plantings furnished the most favorable condition for growth and development. Only under such conditions, he felt, could all the native potentialities of a strain or breed show themselves, and yield something worth saving for the establishment of new strains. Here again we cannot tell how far Burbank was influenced in his views by his own humane sentiments, but both he and Korchinsky agreed in considering favorable living conditions essential for the *appearance* of new variations.

Burbank, having built his own success upon the rigorous selection of " favored " individuals and the ruthless destruction of millions, had implicit faith in the principle of selection. Korchinsky, on the contrary, rejected the theory because it required conditions which he felt to be hostile to spontaneous departures from conventional types and to the preservation of novelties. Korchinsky also presupposed an inner tendency in living things toward higher specialization, a perfecting principle. His emphasis, however, was upon the origin of new forms by *heterogenesis*, that is, by

the appearance of variants that can transmit their new peculiarities. He thus connected up with Weismann's theory of the germinal origin of hereditary traits, and he preceded by a short time de Vries' announcement of the mutation theory.

De Vries

Hugo de Vries, the Dutch botanist, introduced a diversion by announcing the results of many years of study on discontinuous variations. He had attempted to establish new strains of several different species, but he obtained his most striking results with the evening primrose, *Œnothera lamarckiana*. This plant had apparently been introduced into Dutch gardens from North America, and had then escaped from cultivation so that it was growing wild in open fields at Hilversum, near Amsterdam. In the early eighties de Vries observed many of these " weeds," showing the usual variations as to size, vigor, toughness, color, and so on. A few individuals among them, however, showed marked deviations from the normal type. He took to the botanical garden numbers of these deviates as well as of the normal individuals. He grew them from seed and kept careful records of the pedigrees. Year after year he found that most of the seeds in a culture behaved themselves in a thoroughly normal and respectable manner. That is, they produced new individuals like their parents. Both the standard forms and the radical departures from type were true to seed. Yet in a few cases each generation exhibited a number of sports (see Fig. 48).

The new kinds of individuals differed from their parents not in single traits merely, but in all organs and tissues. And they differed from their parents at every stage of development. The evening primrose is a biennial plant. The growth from the seed during the first year ends in a rosette of leaves and a reserve of food in the root. During the second year there is produced a rather tall, leafy stem bear-

ing the flowers and fruit. The new forms differed not only in many details of the tall stem and flowers and leaves, but also in many details of the rosette. That is to say, the step from the parental form to the new form was one of coordinated characters, affecting all the organs (and functions or processes) of the species, not merely one or a few traits.

De Vries continued his observations and experiments nearly twenty years before he announced his new theory of species formation, the mutation theory. His experiments included, incidentally, the independent rediscovery of Mendel's principles of heredity (see pages 287 f). The mutation theory starts out with the first reliable facts of inheritance that we have managed to capture — the so-called laws of Mendel. It goes farther, however, in asserting that the beginning of a new species is to be found in particular individuals, who start out upon life with a distinct break in the continuity of the germinal material. These new individuals have inherited something from their parents, but somewhere in the chain of events something was added, or something was taken away, with the result that the further heritage is modified.

The mutation theory meets the logic of Lamarck's theory, but locates the critical point at which change emerges in another part of the chain. It is not the modified individual that influences the germinal plasm which he transmits. Something happens to the germinal material directly — either through some agency acting from without (for example, a chemical influence, X-rays, temperature) or through some irregularity in the behavior of the chromosomal protoplasm itself (as in non-disjunction, cross-over, new factorial combinations, and so on). Some of these departures from the conventional types will reproduce themselves in a new line. If they can meet the conditions of life, they will establish a new race, type, species — otherwise they will perish, as any unadapted unit.

The mutation theory may be stated very simply: New species arise by discontinuous variation from previous forms. There is a saltation, or jump, beyond the usual fluctuation of characters in the offspring of one or several individuals of a species. The new collection of characters becomes established because each of the new characters (or the combination) is inherited.

This does not mean that the world is suddenly turned topsy-turvy. It does not mean a repudiation of the old aphorisms. De Vries does not claim that we can gather figs from thistles or grapes from thorns. The theory means only that from time to time a plant or animal bears offspring that differ from the parental type in some distinct way and that the new form can reproduce itself.

Basing his conclusions upon facts drawn from the observations of many students of many species of plants and of animals, but particularly upon his own experiments with evening primroses, de Vries summarized his theory as follows:

1. The new species arise suddenly at a single step, without transitional or intermediate forms.

2. New species are generally fully constant from the first moment of their origin.

3. The distinctive characters of the new forms correspond in kind and in degree with those which distinguish from one another old and established species.

4. A considerable number of new individuals of the same sort usually make their appearance at the same time.

5. Although the new types vary in a normal fashion, and frequently transgress the limits dividing them from the parental type, their first appearance bears no relation to the normal or continuous variability of the parental species.

6. The mutations take place indefinitely, showing no special tendency to favor a particular direction.

De Vries believed further that the tendency to give rise to new mutations recurs periodically, but he had no direct evidence to support this supposition.

Advantages of the Mutation Theory

From the point of view of giving a reasonable explanation of how organic evolution comes about, the mutation theory has certain advantages over the theory of natural selection. It is interesting to learn that these advantages were more promptly recognized in this country and on the Continent than they were in England, where the thought of scientists was more completely under the domination of Darwinism, although some of the keenest criticisms of Darwinism had also come from England.

The first advantage of the mutation theory is that it accounts for new characters that are too trifling to be of any value. Such an incipient character may persist, despite its lack of value, until it acquires, through later mutations, an important place in the life of the individual or of the species.

In the next place, the mutation theory contemplates the simultaneous or repeated appearance of many individuals with the same new character. It thus explains how a relatively rare, and perhaps useless, set of traits might get a foothold, or avoid being swamped.

Third, mutations may appear in the form of a new variety or species that is at once adapted to living in an environment somewhat different from that occupied by the parental form. It thus makes possible an isolation that protects the new strain from being swamped or crowded out by the prevailing type.

Fourth, the mutation theory accounts for the appearance of numerous characters that distinguish species from each other but that are not of sufficient adaptive value to be saved by natural selection.

Fifth, mutations may include not only indifferent but even some injurious characters. The existence of such characters in plants and animals is in conflict with the selection theory. If they are not too injurious, however, it is in harmony with the mutation theory.

Sixth, a mutation that affects the time of ripening or maturing would have an immediate advantage in securing an isolation from the parental form (that is, a physiological isolation). Under the theory of selection such a radical departure from the parental character would be a disadvantage.

Criticisms of de Vries

Some of the new forms which jumped out of the seed-beds were certainly distinct from any evening primroses previously observed or described, either in Europe or in America, the original home of the whole group. They were distinct enough from other known forms to be considered "good" species. They reproduced themselves constantly and consistently. Other new forms, however, showed in breeding experiments that they were not constant, or that they were not capable of reproducing themselves. These facts suggested the probability of a hybrid origin. Consequently de Vries and his findings were exposed to the most severe criticisms.

The *Œnothera lamarckiana* form, which de Vries took to be the parent type, was not to be found in this country, although related forms were present in abundance. On the other hand, an American botanist, Bradley M. Davis, was able to produce a *lamarckiana* synthetically! That is to say, by crossing other species of the same genus, he obtained forms like those that de Vries had used as the basis of his experimental evolution. These results in America were taken by many to indicate that the *lamarckiana* was really a hybrid, and could therefore yield the many other forms by virtue of the segregation which we have seen to be characteristic of the offspring of hybrids (see page 239). Davis actually obtained, by inbreeding his hybrids, a number of new combinations of ancestral characters, plants resembling some of the "novelties" which de Vries had found in his cultures. These findings threatened to discredit the mutation theory which de Vries had so laboriously built up.

Mutations Experimentally Established

It may well be that de Vries had committed a serious blunder in mistaking the segregated descendants of a hybrid plant for mutations. The *fact* of mutation has nevertheless been since established for many other plants and animals. More particularly, it has been shown that with each mutation there goes a related change in the chromosomal mechanism of the plant or animal. Generally speaking, therefore, Weismann's theory is supported by concrete facts. Variations in the number or arrangement of chromosomal elements are visible under the microscope. Corresponding to these variations in the chromosomal pattern there are to be observed variations in the structure or appearance of the individual organisms. The idea that nature does actually make saltations, that new types arise completely formed from parents having different characteristics, is now no longer a theory, but an established fact. The theory is simply that *it is in this manner that new species arise.* Progressive divergence in plant and animal forms is brought about by the occasional or more frequent production of mutations.

The most thoroughly studied animal from the point of view of heredity and mutations is the fruit fly Drosophila, which shares with Mendel's peas the glory of having served the scientists in establishing fundamental laws of genetics. In this animal hundreds of distinct traits have been studied, many of them having originated while under observation. The scientist was present at the birth of a new species from an old.

It is commonly supposed that mutations must be very striking departures from the parental pattern, but this impression is due to the nature of the material with which the investigators work. They have to select well defined characters to facilitate recognition, recording, classifying and so on. With the increase in experience and with the accumulation of information it is seen that there are mutations

affecting all organs, and in every degree of magnitude — some so small as to be indistinguishable from the normal individual fluctuation.

Range and Frequencies of Mutations

Mutations have been reported for every system of organs in hundreds of species of plants and animals. Naturally more is known about organisms in the laboratory, in

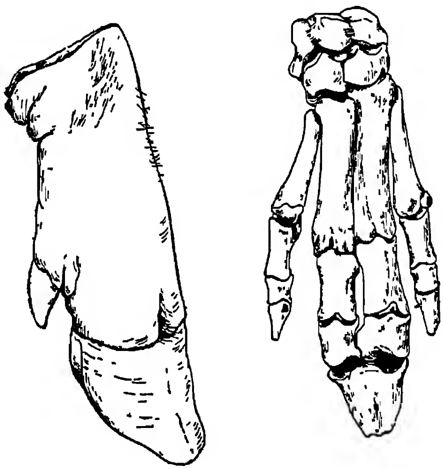
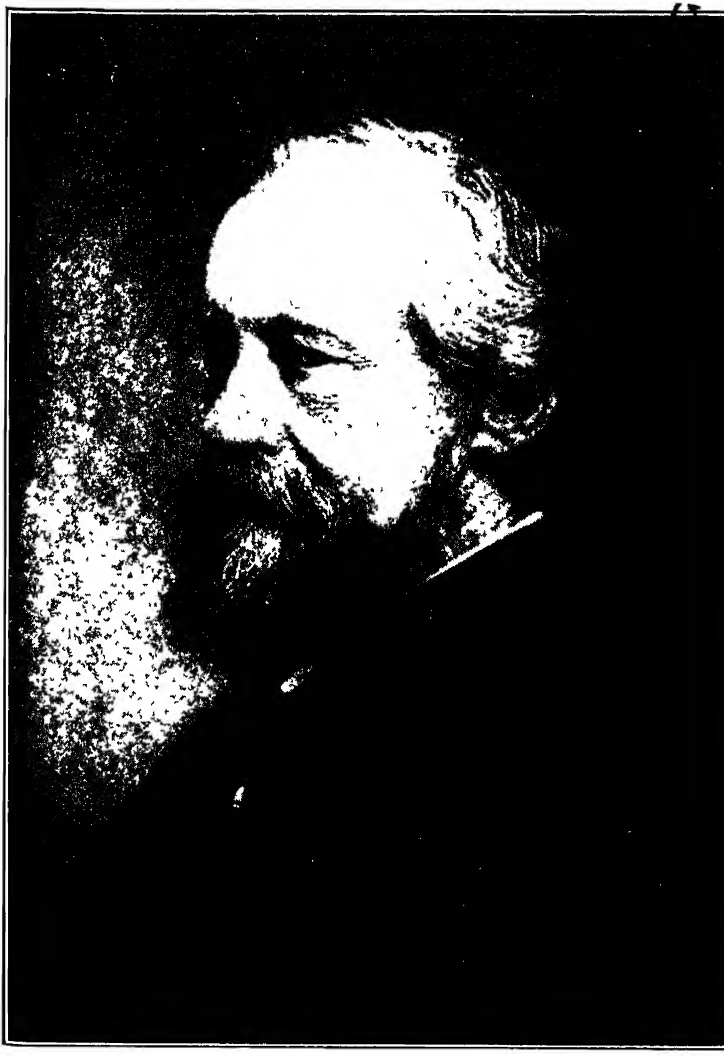


FIG. 97. FUSION OF BONES IN A PIG'S FOOT

Parts that are ordinarily separate in the members of a species are sometimes fused together, as in a pig with an uncloven hoof. After Bateson.

the garden and in the breeding pen than is known about wild animals. The indications are, however, that the same kinds of mutations appear in a wild state, but fail of notice because our attention is not directed to them.

Recessive characters appear as mutations as well as dominant ones; and mutations may show themselves in the loss of some bodily character, or in the fusion of parts, as well as in additions or in gains (Fig. 97). Some well known



Photograph from Dr G H. Shull

HUGO DE VRIES

HOLLAND 1848

dominants that appear as losses are the hornlessness in cattle, the short-fingered hand in human beings, a missing thumb, the bob-tailed cat, and the loss of pigment in certain types of poultry. Some recessive losses are illustrated by albinism in rodents, the loss of color in certain flowers, silky feathers in poultry, and night-blindness among human beings (a condition due apparently to the absence of certain purple pigments from the retina).

Examples of additions are supernumerary digits in human beings, duplications of parts of the foot in cats and in cattle, deeper color, longer hair, longer tail, increased stature, increased branching, feathers on the foot of poultry, the persistence of web between the toes in birds and in human beings, and so on. Additions or accentuations may, like losses, also be either recessive or dominant.

The frequency of mutation is very difficult to estimate since only a rare example of mutation in nature comes to the attention of the scientist. A study has been made of the mutations reported in the most intensively studied animal, the fruit fly, and here it is estimated that *between thirty and sixty mutations* appear in every hundred thousand. This means that in a population of a hundred thousand that number of individuals will show one or more traits diverging from the parental type and able to reproduce the character in subsequent generations. One can get an idea of how great a frequency this is by comparing it with relatively rare events in a more familiar population such as that of one's own city or state. For example, out of every 100,000 human births reported, there are 12 cases of triplets. In a population of 100,000 we should expect to find 42 or 43 deaf mutes, and about 60 blind persons (although many of the latter are not born blind).

It is very likely that there is a great variation as to mutability of species; that is, some stocks are more stable than others, and it is possible that mutations are not so frequent in other species of plants and animals as they are in evening primrose or in fruit flies. Even at this rate of muta-

tion, however, which may seem exceptionally high to us, it is estimated that it would take over a thousand years for all the possible modifications in fruit flies to appear, with the animals breeding at their maximum.

It is probable, also, that some genes are more stable than others. At any rate certain kinds of mutations arise over and over again from the normal wild stock. Thus the wing variation called "cut" in Morgan's cultures occurred over sixteen times and in five distinct types. The wing-character called "notched" occurred over twenty-five times in three distinct types. The white eye occurred over twenty-five times in eleven distinct types, and so on. Similarly, de Vries' cultures of evening primrose showed the repeated occurrence of certain mutations among pure strains of the parental type (see page 184).

The Number of Chromosomes

The peculiar behavior of chromosomes during cell division, during the formation of germ cells, and during the process of fertilization is generally recognized as of great significance in growth and development, in the emergence of the distinctive characteristics of the individual, in reproduction, and in heredity. This peculiar behavior has already been described (page 254) and its regularity has been shown to bear upon Mendel's principles of heredity, as well as upon more recent discoveries in genetics. A great deal of significance has also been attached to the fact that each species of plants and of animals has a constant number of chromosomes (page 251). At the same time it has been difficult, not to say impossible, to ascertain with absolute precision the exact number of chromosomes in some of the more familiar species — for example, man himself. It would seem to an unprejudiced person that if these structures are actually visible it should be a simple matter to count them. Yet it is not a simple matter, but one involving numerous technical difficulties.

In recent years we have discovered further that the number is not so constant, after all. Thus, we have seen that the number may be different in the two sexes. Now it is found that other differences are also present. In some groups of plants and of animals there appear individuals, and whole strains, in which the number of chromosomes is triple or quadruple the number found in the germ cells, instead of simply double (page 253). Or the number of chromosomes may be an even larger multiple of the normal. In other cases there appear individuals in which the nucleus of the cells shows one or more supernumerary chromosomes, or a shortage of one or more chromosmes.

Experimental breeding, combined with the microscopical study of the chromosomes in the plants and animals used, shows that there is a close relation between mutations and these two types of irregularities in the chromosome numbers — that is, the addition or subtraction of one or a few chromosomes, and the multiplication of the entire sets of chromosomes.

The evening primroses supply examples of both kinds of irregularities. In one series the cell nucleus contains one or two supernumerary chromosomes. In each case the individuals present a correlated set of body characters that affect all the organs of the plant. The normal number of chromosomes in the ancestral type, *lamarckiana,* is seven in each germ cell and double this number, or fourteen, in each body cell. In certain new species, however, each body cell contains fifteen chromosomes. These eight species are distinct from each other as well as from the parental form: *scintillans, albida, oblonga, subovata, cana, pallescens, lactua, liquida.* Since there are only seven chromosomes in the germ cell, it is conceivable that seven mutations might arise by the duplication of one or another of the chromosomes. Since there are more than seven of such primary mutations, it is possible that two supernumerary chromosomes sometimes take part in the formation of a mutant.

An explanation for the occasional irregularities in the behavior of chromosomes is found in a study of their division during cell formation, and especially during the formation of germ cells. When the two halves of each chromosome begin to separate from each other, before the germ cell is formed, it may happen that the halves of one of the

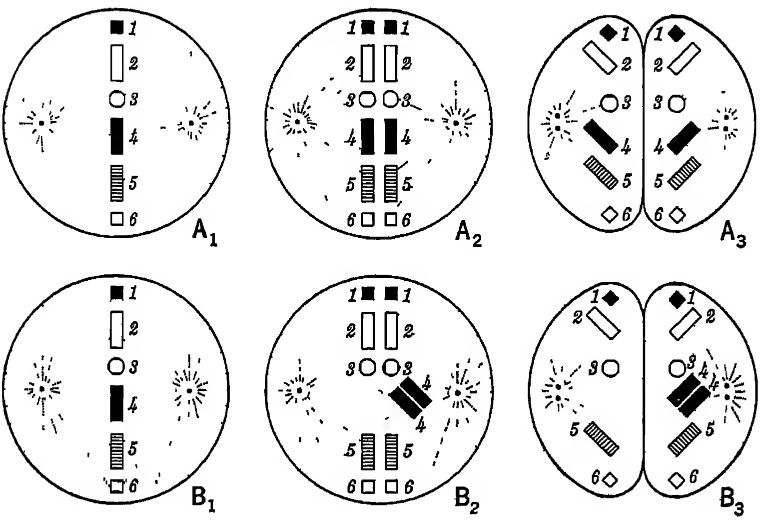


FIG. 98 NON-DISJUNCTION

In the formation of new cells the chromosomes (1–6 in A_1) normally split lengthwise (A_2), move toward opposite poles and become the chromosomes of the daughter-cells (A_3) Various irregularities have been observed to occur, however Sometimes a cell that appears to be perfectly normal (B_1) as to its chromosomes proceeds to divide in the usual way, but the two halves of one of the chromosomes (4 in B_2) instead of passing to the two daughter-cells, remain together, with the result that the two daughter-cells (B_3, which may be two germ cells), are unlike, one of them having a deficiency of chromosome numbers, the other having an excess of chromosome substance

chromosomes fail to come apart. Such non-disjunction would result in producing one sperm, let us say, with a shortage of chromosomes, and one with an excess. In the Œnothera, for example, instead of each germ cell having seven chromosomes, the normal number, there would be one with six and one with eight. The latter, on combining with

an egg having seven chromosomes, would give rise to a new individual carrying fifteen chromosomes in each cell; and the supernumerary chromosomes would affect the development of all the parts of the body. In some cases there may also be double non-disjunction, which would result in the carrying over of two extra chromosomes.

Multiple Chromosome Numbers

In several species of evening primroses, in the thorn-apple or Jimson weed, in wheat, tobacco, and other groups, there has been observed a multiple of the normal number of chromosomes. Thus *Œnothera gigas* has 28 chromosomes, as against the 14 in *lamarckiana*. *Œnothera semigigas* has 21 chromosomes. Since we conceive the chromosome to carry or perhaps to be made up of the material units called genes, all of the genes affecting the development of the individual would be already present, for whatever they may signify, in a single set of chromosomes. It is therefore difficult to conceive how the doubling or trebling of the sets of chromosomes can produce a change in type. We find that in reality the presence of these multiple sets of chromosomes is related to changes in all parts of the body, but chiefly of a *quantitative* sort, that is in the size and vigor of the plant as a whole.

The appearance of multiple chromosomes would seem to arise when an egg, containing say seven chromosomes, is *fertilized by two sperm cells,* each adding seven more chromosomes to the total. That this does sometimes happen has been actually observed in several species, although the multiple chromosome numbers may arise in other ways.

The presence of multiples of the basic chromosome number, called polyploidy, has been reported in many groups of flowering plants, both wild and cultivated. Among them are the banana, the mulberry, the pineapple, varieties of wheat, oats, sugar cane, maple, tobacco and dahlia. The multiples run sometimes as high as eight or ten times the

basic number. Eight-fold types have been found in roses and maples. Ten-fold chromosome numbers have been found in chrysanthemums and in sheep sorrel. Other high multiples are present in species of hawthorn, raspberries, hawkweeds, hardhacks, in chrysanthemums and other genera of the compositæ.

Chromosomes and Evolution

That the chromosome number can be changed has been repeatedly shown in many lines of plant and animal studies. The relation of the chromosome number to the characteristics of a species is beautifully shown in the fact that in some genera one species differs consistently from another both in the outward characters that are obvious to all, and in the chromosome number. Thus, among the sedges many species have been described in the genus Carex; but later researches show that these species differ from each other in their respective chromosome numbers. The following chromosome numbers have been recorded: 9, 15, 16, 19, 24, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38, 40, 41, 42, and 56. (These are the numbers in the germ cells; the number of chromosomes in the body cells is double the given number in each case.) In a series of the genus Crepis, related to the thistles, chromosome numbers varied among different species as follows: 3, 4, 5, 6, 8, 9, 11, 20. As there are over 250 species of this genus known, it is not likely that each one has a distinct chromosome number; but it is certain that each group of characteristics in a species corresponds to a material structure or arrangement in the chromosomes of the cells, including the germ cells from which the individual originates.

Another type of chromosomal change is represented by the breaking up of long chromosomes into two or more permanently separated pieces. This has been observed in some of the true primroses and in some of the lilies. In fruit flies, on the other hand, and in other species, chromosomes

sometimes fuse end to end. In the Japanese violet large chromosomes seem to have been formed by the fusion of smaller ones, which are still separate in related species.

Irregularities in the behavior of chromosomes may occur earlier in the history of the germ-cell lineage, resulting in the production of numerous aberrant eggs or sperms, and leading to several mutations from the same parentage. If the chromosomes fail to divide in the usual manner in the body cells, the result would not show itself in the progeny, but, if it occurred early during the development of the individual, it might show itself in some abnormality that is *not* transmitted to the offspring at all.

Genes and Mutations

More striking and more directly useful to the student of experimental genetics and evolution are changes in outward appearance and behavior that can be traced to changes in the genes, rather than to changes in whole chromosomes. A modification of a single gene may be expected to produce slight changes in all parts of the developing body, with a more distinct departure from the parental type in some particular organ or character. This marked variation would therefore attract the attention of the student and serve also as a means of recognition in further studies. It is from the studies of gene mutations that we have learned most about the principles of heredity, and about the actual origin of species by mutation.

In the cells of a plant or animal body, the chromosomes, as we have seen, are paired. One member of each pair is derived from the mother through the egg, and the other from the father, through the sperm cell. If a change takes place in a gene, it would be in *one of a pair* corresponding to certain combinations of characters — for example, one making for longer hair or for shorter, for straighter hair or for kinkier, for pigmentation or for whiteness, and so on. Now, this change in the gene might come about at the time

when a germ cell is being formed. There would then result a single egg with the altered gene, or a couple of sperm cells. If the change took place earlier, it might result in the formation of a considerable number of either eggs or sperm cells containing the altered gene. In any case, the odds are against the change ever manifesting a new condition in developed individuals resulting from them unless the gene change (1) came very early and produced very many eggs or sperms of the new kind, and (2) was related to a dominant trait.

If the change in the gene makes for a recessive, the new gene would be reproduced in the body cells as well as in the germ cells, but would show nothing in the succeeding generation of developed individuals. It could be multiplied for several generations and not show anything at all in the offspring. When, however, there were so many individuals bearing this recessive gene that males and females carrying it finally mated, the corresponding character would appear as a freak or a mutant. This corresponds to de Vries' statement that a mutational change would be latent for several generations and then appear suddenly in one or several individuals manifesting the new character. What has been latent is a modified gene. This, being recessive, could not bring about any change in the appearance of individuals, although present as part of the heritage, and carried on from generation to generation in a certain proportion of the population, in accord with Mendel's principles of the purity of the germ and segregation.

If such a gene mutation is dominant, however, it may manifest itself in the first generation. Whether or not it continues to multiply would then depend upon the numbers in which it first appeared and upon the relation of the character to living conditions. If it were useful, or even indifferent, it would continue. Otherwise the disadvantage would lead to its extermination. There is no danger of the new gene being swamped in the old sense, since it retains its qualities or capacities in a "pure" state.

Mutation and Natural Selection

At the time of the publication of *The Origin of Species* it was assumed that heredity is a process in which the characters of the two parental lines are blended. It was then possible to show that a new character would necessarily become so diluted after a few generations that, unless it had outstanding advantages in the struggle for existence, from the very first, there was no chance for it at all. If, however, the new characters are already of such outstanding advantage, it was argued, we do not need to assume that "natural selection" is responsible for the accumulation of minute advantages, to account for the origin of new species. The mutation theory, with the known facts of genetics, obviates this difficulty of the selection theory.

The observation has been made that each mutation concerns not merely the outstanding character that holds the attention of the experimenter but many other physiological as well as structural details. This fact simplifies our understanding of the origin of species by mutation, for it solves Darwin's problem of "correlation." The marks by which we distinguish species are not, in general, the characters that are significant in the "struggle for existence." Yet they are as constant as the essential organs and processes for maintaining life. The theory of origin of mutations through a change in a gene reconciles these two sets of facts. The classifiers and experimenters have naturally emphasized obvious and superficial traits. Survival has depended upon more deep-seated structures and capacities. In so far as a plant or animal is fit to live and reproduce, it is because of the latter class of characters; but these are also manifestations of the same genes as bring about the superficial structures and markings. A mutation in such a gene may bring about more or less far-reaching changes in both kinds of characters. This would explain why most mutations are actually injurious rather than useful. An established species must have survived, with its characteristic structures and

functions, thousands of generations of the kind of elimination which Wallace and Darwin assumed, but only with respect to significant features, not to those that distinguish the various species from one another for the casual observer.

How Mutations Are Brought About

Evolution by mutation would mean the occasional introduction, into the germ plasm of a line of plants or animals, of new factors capable of influencing the development of characters already present in the species.

Advantageous characters would presumably survive and become assimilated in the constitution of the strain or race. The new type would become thereby established, and would serve as the basis for still further mutations. Each individual is thus the potential jumping-off point for new possibilities in evolution. This development of de Vries' theory and of the experimental studies of the last thirty years is in accord with Weismann's speculative ideas about the germinal sources of hereditary changes, although Weismann himself remained a staunch advocate of natural selection to the end.

Germinal changes, that is, changes in the chromosome and in the genes, may bring about a new trait not only in every part of the body, but at any stage in development. It might result in increased growth or in smaller stature; in prolonging the duration of life or in shortening it; in advancing the age of maturity or in accelerating the development. A germinal change might affect a character that appears early in infancy, or one that is manifest only after maturity. Recent studies in Europe have shown that certain qualities of the human voice are inherited in Mendelian fashion; but these characters appear only after puberty.

Whatever the cause of such germinal changes may turn out to be, it is not necessary to think of mutations as adding or subtracting such a very small detail as to leave the

old and the new differing in an "almost imperceptible degree." For example, we do not need to assume that the evolution of the zebra's coat pattern was attained in the course of many generations by the addition of one stripe at a time: the stripe pattern could have appeared at one step, by a change in a single factor or gene.

It has long been known that animals exposed to the action of X-rays may sustain injuries not only in the body tissues but also in the reproductive organs. Such exposure sometimes results in sterility, and under certain circumstances in the production of abnormal progeny. Systematic experiments with mice have shown definitely that the chromosomes of the germ cells are influenced by X-rays acting upon the body of either the male or female parent; and that the abnormalities in the progeny are accompanied by similar disturbances in the chromosomes of the body cells. There have been several series of experiments in which the action of alcohol upon the parent was followed for several generations with results that indicated some injury to the germ plasm There is also some evidence that lead absorbed into the body may, without poisoning the parent, influence the germ cells and give rise to abnormal offspring.

These modifications of germinal material through action upon the parent have been described as "racial poisoning," although their precise operation is not understood. Many lines of experimentation are under way in the attempt to clear up the problem, since the influence which the modified body may exert upon the germ plasm is an important consideration in connection with the problem of the transmission of acquired characters. The positive evidence available may be taken to show that the germ plasm is not completely shielded against influences that act upon the body. It does not, however, warrant us interpreting the facts as pointing to the transmission of parental acquirements, since in these cases the effect manifested by the offspring is totally different from the effect manifested by the parent. For example, intoxication of the father leads

to defective eyes in the offspring; exposure of the mother to radium brings about congested capillaries of the skin of baby mice, and absolutely nothing corresponding to that in the mother.

Mutations and Evolution

We have already noted the various alterations that can take place in the chromosome material, including the genes (pages 272 ff). Some of these alterations represent recombinations of factors already present in the hereditary constitution of the strain, and bring about the development of exceptional individuals. Strictly speaking such individuals would not now be considered mutants. With each novelty it would be necessary to determine, by means of breeding experiments, the composition of the hereditary make-up and to find out whether the new phenotype represents also a new genotype. It has been adequately established as a general fact that true mutations do occur, and it is from these that evolution takes its start in each case. Each of de Vries' six major propositions regarding evolution by mutation is supported by the facts; and there are no known facts that contradict them. It is too soon, however, to say that this is the exclusive manner of evolution; and there remain many unsolved problems, even if the mutation theory should be completely established.

It has been pointed out that many new ideas meet with opposition not so much because they are in themselves unreasonable or improbable, but because they conflict with a prevailing mode of thinking — what we like to call "common sense" even where it represents only common ignorance. The theory of mutation illustrates this especially well since it came into conflict not only with a certain passive resistance to evolutionary thinking, but also with the wide diffusion of ideas about "evolution" as a very gradual process — the very idea which Darwin stressed by his frequent reference to the doctrine that Nature makes

no jumps. We had become accustomed, also, in the discussion of economic and political ideas, to contrast "evolution" with "revolution." So many of us were evolutionists in the comfortable indifference that was satisfied to leave everything to "natural law," that every change proposed threatened to be "revolutionary." Along came de Vries at the end of the century and said in effect that this acceptable process of evolution is actually a step by step process — and each step is a revolution!

This point of view had in the meantime made a congenial place for itself in the minds of many people through the development of new theories regarding the constitution of matter. Whereas the elementary approach to the constitution of matter assumes a certain continuity, the atomic theory at the end of the Eighteenth Century started to accustom the civilized world to the idea that matter is made up of infinitely small disconnected particles. But a century later investigators were already at work breaking the atom up into still smaller hypothetical units, with a still greater proportion of empty space. These newer theories of matter emphasized especially not merely the discontinuity of matter as an existing something, but also the discontinuity in the change of one kind of matter into another. Everything goes, when it goes at all, by jumps.

Perhaps this theory of evolution, like its predecessors, will also have to yield to increased knowledge. At the present time it harmonizes not only with the relevant facts of observation and experiment, but with the temper of the scientific world. Our reliance upon "natural laws" and upon the principle of uniformity have become reconciled to accepting the "new" as a normal outcome of the "old."

Chapter 13

The Inward Urge to Change

MOST people have no great difficulty in thinking of the material universe as in constant flux. We accept the universality of cause-and-effect relationship, and this furnishes a satisfactory "explanation" of the physical events. We are satisfied to accept the interpretation of what happens on a strictly mechanistic basis. We have confidence that "science" can measure and predict, and eventually control, the purely physical or chemical realities of the world.

The difficulty arises when we attempt to think mechanistically of living things, of their activities as individuals, of their adaptations to their complex surroundings, of their rise and extinction in the past, and of the suggested appearance of *new* forms from different parental forms. The convergence of the evidences from various branches of scientific study leaves no doubt in the mind of the biologist or of the paleontologist that *evolution* (in the sense here used) *has actually taken place.* The numerous attempts to explain what seems to have happened have not, however, united the opinions of informed specialists on a scientific or cause-and-effect theory. Each of the more prominent theories is plausible enough, but none accounts for all of the facts in a satisfactory way.

Divergent Theories

Lamarck's theory, the transmission of the effects of use and disuse, stands to reason, as we say. Nothing could be more satisfactory than this logic: just as the individual

plant or animal undergoes, in the course of his development, the kind of alterations that fit him to further life in the given circumstances, so the species adapts itself to changing conditions from generation to generation. Is it true that the effects of the individual's response to environmental stimuli and disturbances are passed on to the offspring? If so, both adaptation of species and progressive evolution can be accounted for — at least with respect to such characters as appear in the individual because of some active processes. Unfortunately for this special theory, it not only fails to account for many characters in animals as well as in plants that are purely "passive," but it fails to find support in any positive evidence that the acquired traits are ever actually reproduced in the offspring. Even the newer modifications of the theory, which look to a parallel modification in the germ and in the parent's body, have so far failed to marshal supporting evidence of a satisfactory kind. There is, however, the adjustment of the individual during his lifetime; and there is the progressive adaptation of species by modification in successive generations. The parallelism remains as a matter of observation, even if we cannot explain just how it or either of its members comes about.

Darwin's theory of natural selection also stands to reason. After all, the great variations among individuals, including variations in adaptiveness to given surroundings, cannot be without effect in determining survival and reproduction. Perhaps the struggle for existence is not so severe as Darwin and Wallace supposed. Perhaps it is not along the lines that had been assumed. But surely there must be a differential death rate or survival rate. That is so obvious that it leaves no room for argument. As we have seen, however, the fact of differential survival, or of selection, accounts neither for the origin of variations, nor for the origin of adaptations. The theory may be but another way of restating the fact that organisms are adapted, and that only organisms which are more or less "fit" can possibly continue to live and reproduce.

De Vries' theory of mutations, elaborated by later experimental research, accounts for the origin of hereditary departures from ancestral models. It does not stand to reason — that is, it is not in accord with our familiar experience — that one "kind" of living thing should give birth to another "kind." *If*, however, there are mutations, and *if* they reproduce their novel characters, and *if* the new types are capable of maintaining themselves under the prevailing conditions, then the theory explains evolution, in the sense of descent with modifications. Unfamiliar as the concept of progression by jumps is to most of us, we may only ask, What are the facts? As we have seen, the mutation theory, within the limits of its more cautious advocates, is quite in accord with the facts of observation and experiment. The theory does not account for the origin of life nor for the distinctive properties of protoplasm. Especially does it fail to throw any light upon the origin of adaptations.

Reconciling Divergences

The advantages and shortcomings of these leading evolution theories have naturally lead to a great deal of controversial discussion among the specialists. And occasionally those of us who are not so well informed also take a hand in it. There are some who feel that every serious idea which seems plausible must have some "truth" in it. They accordingly attempt to reconcile theories that appear mutually incompatible — just as we sometimes struggle to reconcile our prejudices or preconceptions with the obstinate and embarrassing facts. Natural selection at least can be harmonized with mutation. We have seen that de Vries himself believed his contribution to consist of showing that the variations upon which natural selection acts as a sieve originate by mutations or jumps. Whichever theory one may favor, however, all have certain things in common: They all seek to formulate a cause-and-effect principle which will account for the progressive modification of living forms in the

course of time. They also assume that variation itself is not determinate, but may take place indifferently in all directions. They all look upon evolution as having brought about a succession of forms that show, in many branches, a definite or determinate direction.

Directed Evolution

The fact that evolution, as actually observed in the sequence of forms, is determinate has brought forth an entirely different set of theories. Carl von Nägeli, a German botanist, issued in 1884 a very searching criticism of Darwin's theory of natural selection. In this he proposed an "internal perfecting principle" to account for the tendency of living things to evolve in a definite direction. There are two serious objections to this theory. (1) It fails to account for the very many cases in which a large number of species seem to cluster around a type and to diverge in all directions. (2) It fails to account for the many cases of degressive evolution, such as the deterioration associated with parasitism, the loss of unused organs, and so on. More than that, however, the theory does not lend itself to scientific use. It assumes what is essentially a mystic force that defies objective study and further analysis. It is just the kind of "explanation" that Darwin sought to avoid in assuming that variations are "chance" events (see pages 340 and 367) and in explicitly disavowing any suggestion of purpose or direction in natural selection.

A few years later (1888), Theodor Eimer, who had carried on extensive studies on the pigments and patterns of butterflies and lizards, propounded another theory of *orthogenesis*, or directed evolution. In this he combined the action of environment, the transmission of modifications, and various subsidiary theories to account for the observed fact that the transformation of species is frequently in definite directions over a long period of time. Eimer attempted to explain both variation and heredity as due to the

reaction of living matter to external physical and chemical conditions. He attempted to account for adaptation and orthogenetic evolution as due to internal properties of living matter, specifically to the "laws of growth." He acknowledged the effects of natural selection in extreme cases. He believed, however, that the outcome of the evolutionary process would have been substantially the same if there had not been a severe struggle for existence. The constitution of species is

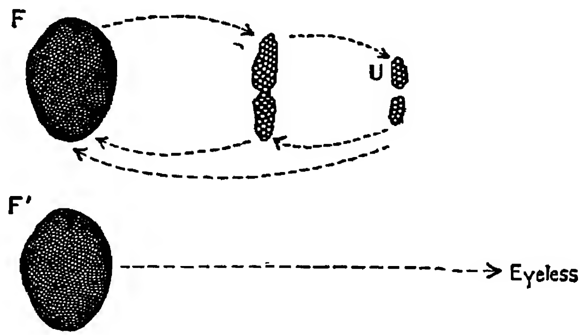


FIG 99. BAR-EYE IN FRUIT FLIES

Among fruit flies used in the experimental study of heredity there have appeared mutations in which the eye surface is reduced to a mere "bar", and there have also been mutations showing various degrees of reduction A series of flies can be arranged showing a continuous gradation from the smallest to the largest eye From actual observation, however, it is found that each of the various forms can arise from the normal wild type, and also that there can be reversion to the round eye. The arrows indicate sources and directions of observed mutations After Zeleny

such, Eimer thought, that determinate variation and determinate evolution ensue directly.

The paleontologists have had the best opportunity to observe the long-time facts regarding plants and animals. They are disposed more than any other group to think of evolution as determinate. Orthogenesis almost forces itself upon the thought of one who sees the long succession of snails, the coiling of ammonites and nautilus through the ages, the increase in size of reptiles, the progressive elaboration of tusks among the elephants, the steady overgrowth

of horns among the deer and elks, and so on. One is impressed with the tendency for these special forms or organs to push on and on to greater size or complexity.

In a species manifesting gene mutations there sometimes appear several mutations of the same gene with the result that individuals or lines show a series of graded characters. In the case of the fruit fly there is a short series of gradations between the fully formed compound eye and the complete absence of eye, related apparently to a change in a certain gene (Fig. 99). Such a series strongly suggests the operation of some orthogenetic influence. As we have already seen, however (page 229), there are cases of such series in which the successive members are known to have originated independently. That is to say, we may have a graded series without necessarily assuming an orthogenetic tendency.

Facts and Implications of Orthogenesis

For several years before and after the turn of this century, students under Professor Vernon Kellogg at the Leland Stanford, Jr., University, recorded the wing pattern of the beetle *Diabrotica soror* found on the campus (Fig. 100). During ten years there was an obvious shift in the prevailing color pattern, as shown by the statistical record (Fig. 101). There was nothing in the circumstances to indicate a selective process at work. There was no apparent advantage to the insects in one pattern as against the other. Dr. Kellogg interpreted the results as an indication of orthogenetic variation, unrelated to the struggle for existence or to any discoverable external conditions. Other cases have been reported both among plants and among animals under direct observation; and Luther Burbank, who had exceptional opportunities to note variations in large numbers, was convinced that variation is determinate, although he found enough indeterminate variations among the plants which he cultivated to yield a multiplicity of new forms for every species.

Among the paleontologists the evidence is equally convincing. The progressive change in successive periods recorded in the fossils is, for the layman, particularly impressive among the horses, the camels and the elephants (see Figs. 8, 9 and 10). Professor Osborn states very definitely that after a line of mammals starts to become specialized in a given direction, acquiring more and more distinct structures, and

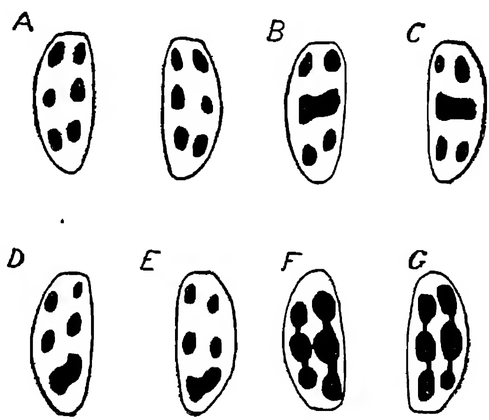


FIG. 100 VARIATION IN WING PATTERN OF THE CALIFORNIA FLOWER BEETLE DIABROTICA SOROR

There are commonly six distinct spots on the wing case, A. The dots may run together crosswise, B, C, D, E, or lengthwise, F, G After Kellogg and Bell, from Jordan and Kellogg, Evolution and Animal Life, published by D Appleton & Company

presumably corresponding habits, it tends to continue in the same direction until it has gone beyond the point where the "improvement" is of value. As a result of such overspecialization, many lines of mammals (and of other vertebrates also) have died out.

Incidentally it is of interest to note the difficulty of adhering consistently to a single theory as an adequate "explanation" of the very complex facts of evolution. Professor

Osborn points out that the Neanderthal race (see page 195) probably lived in a semi-tropical region. This is inferred from the association of the skeletal remains and stone implements with fossils of elephant, rhinoceros, hippopotamus

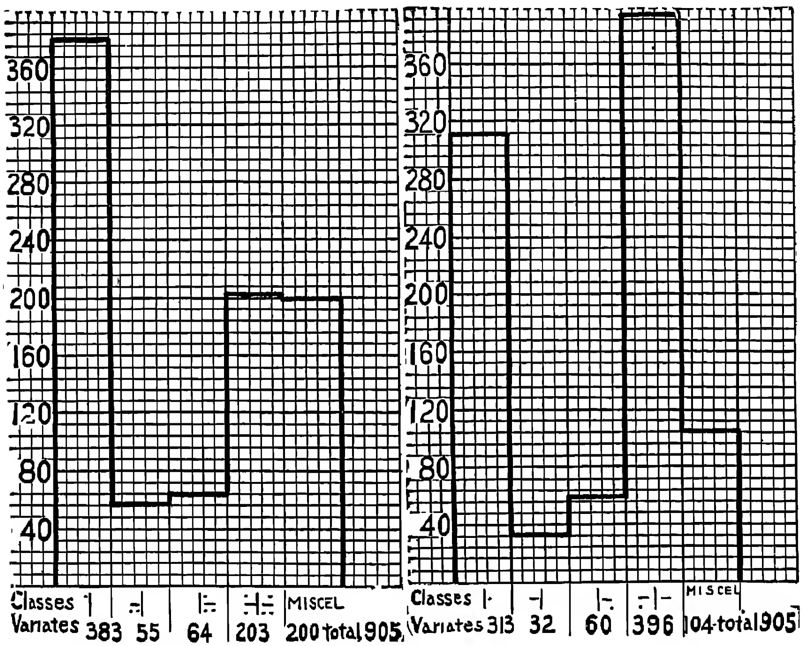


FIG. 101. DETERMINATE VARIATION IN WING PATTERN

The four most frequent types of wing pattern in the California flower beetle, *Diabrotica soror,* were recorded from year to year In 1895, 383 out of a total of 905 (42 3%) had the six dots distinct on each wing, and 203 (22 4%) had the middle dots on each wing run together crosswise Six years later there were 313 beetles of the first pattern, or 34 6%, and 396 of the second type, an increase to 43 7% This shift in the proportions of the various patterns continued over a period of ten years After Kellogg and Bell, from Jordan and Kellogg, Evolution and Animal Life, published by D. Appleton & Company

and other such animals. The available facts point to life in fertile river bottoms, where the vegetation was luxuriant and game and food abundant for man. Under these circumstances the struggle for existence must have been relatively easy, and there " was no pressure for the selection of

superior intelligence." And Professor Osborn finds it "surprising that under these circumstances the Neanderthal brain attained the large dimensions which threw even the genius of Huxley off the track as to the very primitive character of this race." But why is this surprising? We may observe the *outcome* of the various processes, both known and unknown, at work and leading to the phenomena which we call collectively "progressive evolution," or development in rather well defined directions. We may also distinguish between these end results and hypothetical causo-mechanical *factors* from which result or emerge determinate variations, and which we call for convenience "orthogenesis." *If*, now, there is actually at work an agency that brings about determinate variation or directed evolution, as Osborn believes there must be, then we should not be surprised at the relatively rapid evolution of the human brain and of the concomitant mentality. Somewhere in the past there must have emerged a situation in which was inherent the orthogenetic development of man, the inevitable development of man, as Nägeli would say.

We should not be surprised, furthermore, since we know nothing of the circumstances that led to hypothetical mutations in the direction of larger brains. Osborn, in his writings, sometimes combines orthogenesis with natural selection. At other times he sees orthogenesis at work independent of natural selection, or even in spite of natural selection. It may be, however, that orthogenesis is merely a *description of what* the students of the facts have seen, rather than an *explanation of how* the changes have come about.

Explanations

It is frequently difficult to distinguish between a description and an explanation. What do we mean when we "explain" an event or a fact? What is a "good" explanation-

tion? Everybody wants satisfactory answers to the question "Why?" And most attempts to answer a question beginning with *Why,* start with *Because.* Generally speaking, we have come to think of cause-and-effect relationships in two different ways, what we may call the mechanical and the mental. And there are two corresponding types of explanation.

The mental type of explanation is illustrated in our interpretation of human conduct in all sorts of everyday situations. We say, for example, I stopped because I heard the whistle; or, The child cried because he hurt his finger. We attempt to answer the question "Why?" by reference to a purpose, or a reason, or a desire. We interpret the actions of buyers and sellers, of lovers and criminals, of candidates and voters, of beggars and princes, by assigning motives, such as we can understand because we experience them ourselves. People act as they do *because* they have in mind a desired end, and action is explained by a supposed state of mind.

Whether or not our interpretation of motives is sound or adequate, it is but a short step to transfer it to other living things. And then we catch ourselves saying, The birds are going south to avoid the cold winter; or, The caterpillar crawls on the under side of the leaf because he is afraid to be seen; or, The root of the plant grows downward through the soil in order to reach the water — or downward through the water in order to reach the soil. In hundreds of situations we can observe in a plant or animal an activity having an obvious relationship to the needs of the organism, or of the species. And at once we "explain" the action by reference to the possible or probable use.

Most of us go a step farther and transfer this type of interpretation to all kinds of events. We assume useful ends as sufficient to explain everything. It rains *because* our crops need the water. Night alternates with day *because* we can sleep better in the dark. The rosebush has thorns *because* the flowers need protection from rude boys.

Modern science has for the most part avoided this type of interpretation of events observed in the physical and chemical materials and processes. We have learned, that is, to give what is called a mechanistic account of what our eyes have seen. We do not say that the apple falls from the tree because it has a certain affection or attraction for the earth. We accept the fact that things " fall " and we measure the velocities and the forces of falling and so build up a set of " laws " of gravitation. We do not say that an acid neutralizes a base because of any inherent attraction or hostility. When we do use such terms, we are aware (or should be) that we are speaking metaphorically. We attempt to analyze and measure and describe as objectively as possible. We have developed a mode of thinking of events in such relatively simple terms as are employed in mechanics: pushes and pulls of various degrees, with consequent movements of masses of matter, in specified directions, at measurable velocities. We have learned that this method gives us reliable results in dealing with many systems of material things. Although we do not know very much about the nature of the various kinds of " energy," we find it satisfactory to assume that they are interchangeable and fixed in amounts. We find it satisfactory to " explain " many kinds of events in terms of energy and matter — that is, in terms of mechanism.

Mechanism and Origins

These two modes of explaining may be thought of as being respectively an approach from above and an approach from below. Let us take a familiar example. After one engages in brisk exercise, the heart beats faster: this is a fact. We may explain it by saying that there is need for more oxygen, or for more rapid elimination of carbon dioxid. Or we may explain the fact by saying that the change in the chemical condition of the blood accelerates the heart through a special action upon a certain nerve center. In one

case we are restating what happens in the terms of the whole body and its needs. In the second case we are restating what happens in terms of specific details whose relation to one another we can understand as *mechanism*. It goes without saying that every event can be described and explained in these two ways — and that one may be as " true " as the other, provided we stick to the facts.

Movements of levers and pistons, of wheels and screws, of valves and springs, are " explained " in thoroughly mechanistic terms. It is a rare individual who seeks to go behind the facts to find out what makes things behave as they do. The chemist and the student of the atom and the molecule do indeed go somewhat farther behind the scenes than does the engineer, but these also use the methods of mechanics. They think in terms of particles and forces, of measurable movements, of the transfer and transformation of energy. The success of these scientific pursuits has so impressed the world for over a hundred years, that their methods have naturally been imitated by those concerned with other problems. The biologists, especially, for a hundred years, have attempted to capture the virtues of mechanistic science. In these attempts they have not only produced useful results in the way of collecting and analyzing fundamental facts about living matter and living organisms, but they have cleared away a great deal of mental rubbish that stood in the way of clear thinking.

Among the consequences of this adventure, however, has been the setting up of rather arbitrary standards of what constitutes scientific thinking and the rather arbitrary insistence upon one kind of " interpretation " to the exclusion of the others. The result has been that certain scientists have overreached themselves and have come to an impassable barrier to further investigation. This is illustrated by such problems as that of the origin of life, of the relation of life and mind. On experimental grounds we have today no knowledge of life except such as is derived from preëxisting life. Yet on the theory of evolution, which tries to encompass

the whole history of the universe, non-living matter must have preceded living matter, and this in turn must somehow have " evolved " out of the former.

St. Augustine, knowing nothing of chemistry or biology, had no difficulty in supposing that the act of creation so constituted matter that in good time the living would emerge out of the non-living. Cuvier, having no difficulty about accepting the continuous or spasmodic interference of the deity in the affairs of this world, could comfortably contemplate not only *a* creation of living from non-living, but a whole succession of such creations. The chemist, however, or the physiologist, knowing what he does, can only speculate on the many kinds of matter that are intermediate between the unquestionably inorganic, and the unquestionably living. With the assumption of continuity which constantly influences his mental processes, the transition from the non-living to the living is to him unthinkable — and he is not ready to concede a miracle, or a special intervention of a creative act until he has exhausted every possibility of explanation by rational and scientific (that is, mechanistic) means.

Mechanism and Purpose

It is for these reasons that most scientific students of biology and of evolution have avoided all forms of " vitalism " as an aid to understanding. It is not that a scientist has to be a " materialist." Or that one who uses the mechanistic method of research and interpretation can say with any assurance that a " vital principle " or a " guiding purpose " does not operate in the world. It is only that the assumption of purposes and vitalisms obstructs further research and confuses understanding. The scientist, as such, has to take the facts of the world as he finds them, and he has to manage them as best he can. Experience has taught him that he manages most effectively when he follows the method of " mechanics " rather than when he follows the method of " purpose."

We have seen that there are many theories of evolution, and that the earlier ones for the most part introduced an element of purpose — whether of an outside agency, or of an internal one. In either case such an assumption leaves us entirely in the dark when we seek to understand *how* things work, or *how* events come to pass. We can see that it is one thing to accept the explanation of rain, for example, that it is designed to meet a certain need, or that it is provided in order to carry out a certain purpose; but that it furnishes a different understanding to explain the weather in terms of changing temperature and humidity. The latter type of explanation still leaves us in ignorance as to *why* water vapor condenses to liquid as and when it does, or as to *why* liquid changes to vapor at a certain temperature, or *why* the atmosphere will hold only so much vapor and not more. In short, the mechanistic view answers for us only questions regarding the *how*, but cannot answer *why*. On the other hand, the answers which men attempt to give to the question "*why?*" do not lend themselves to scientific scrutiny and further elaboration. They may satisfy because they are reasonable, but they cannot be verified or tested.

The scientist accepts the facts as given and seeks to find the uniformities in the behavior of materials and forces; and these uniformities we designate "laws."

Law and Miracle

We have been taught to think not only in terms of cause and effect, but also in terms of continuity. We have been impressed with the uniformity of "laws" in the universe and are therefore wary of "explanations" that seem to violate principles of consistency or unity. Evolution would offer no difficulty if we were prepared to believe in miracles, if we could believe, for example, that rabbits could be born along with kittens from a mother cat; but such miracles are unbelievable to one who knows the elementary facts — and uniformities — of mammalian reproduction.

The attempt to apply mechanistic thinking to life and evolution, however, is constantly running into such difficulties. On the one hand, evolution as a historical process has meant continuity, gradual change, uninterrupted sequence of cause and effect. On the other hand, the accumulated facts and the new theories now require us to contemplate discontinuity. Is not this a substitution of miracle for law?

It has taken long ages to liberate a comparatively small part of the human race from reliance upon miracles, both as a means of understanding and as a means of practical control of affairs. The cultivation of the concept of "law" has meant substantial progress in thinking and in elevating the spirit as well as in yielding concrete values through technology and industry. It is possible, however, that this has imposed upon us a new dogma that in its turn obstructs further growth.

We find again and again that our mechanistic explanations will not explain satisfactorily the more complex phenomena of life and mind. We are tempted therefore either to give up the effort as futile, and to fall back upon magic and miracles, or to invent categories of forces and agencies that do not let themselves be treated "mechanistically." Yet the only demand which principles of scientific method make upon us is that of uniform causation.

It is not necessary that we shall be able to explain a mutation in terms of elementary chemistry; or that we shall explain mental processes in terms of levers and valves. It is necessary only that whatever uniformities we discover in any order of events shall be truly universal *for that order.* For example, a push against an object and the consequent movement represent an event which we can explain in cause-and-effect terms. A push by one man's foot against another's toe and the subsequent movements, which may be very intricate indeed, also present an event which we can explain in cause-and-effect terms. Yet nobody supposes that the mechanism of push-and-movement is the same as the mechanism of stimulus-and-response, however simple

the latter, or however complex the former. In so far as we know the uniformities involved in stimulus-response processes, we are dealing with law (or mechanism, as some scientists will insist) and not with miracles, however hopeless it may be to explain stimulus-response in terms of push and pull.

However complicated our problems may become, the scientist will prefer to adhere to the mechanistic method. He feels that once miracles are admitted, clear and consistent thinking becomes impossible, since they imply a transgression of the uniformities, an intrusion into the orderly scheme of things.

It must be acknowledged that physics and chemistry have so far failed to " explain " the origin of life, the distinctive properties of protoplasm, the relation between mind and matter. This failure, however, may not be due to any shortcomings or defect in these branches of science. It need not be due even to the unreliability of the mechanistic method of attacking problems. It is at least conceivable that the fault lies in our transferring mechanically the formulas and principles and laws developed by physics and chemistry to a different order of facts and problems, instead of applying the mechanistic — that is, the causo-mechanical methods of research — to the facts of this more complex order. Mechanical thinking and mechanistic thinking may not be the same.

Specialization of Knowledge

Specialization in research has made possible the intensive study of restricted phenomena and the discovery of usable laws and uniformities within narrow fields. It has at the same time led to initial misunderstandings and suspicions and has resulted in separating the thought of different classes of workers. The chemist, for example, makes sure of certain uniformities in his special field and has a great deal of confidence in " mechanistic " explanations of what he finds. He cannot, however, have the same confidence in

the " laws " of the psychologist and of the economist, since the latter do not make clear a mechanism which the chemist can follow.

The physicist derives his " laws " by the observation of physical phenomena: He analyzes the actions and interactions of material bodies, of liquids and gases, under various conditions, under the influence of various forces. The uniformities which he finds he accepts as in the nature of the material with which he is working. He records what he sees, and he sees what comes to his eyes, without prejudice. The chemist pursues similar methods. These prosaic concentrations upon the commonplace materials that we find everywhere at hand have revealed striking and astonishing facts. Yet it was impossible to know in advance, for example, that a current of electricity passing around an empty space would make the hollow behave like a magnet. It was impossible to predict that a discharge of electricity through a vacuum tube would result in shooting out rays that could penetrate wood and leather and human flesh. From a thorough study of the qualities of silver and bromine, nobody could possibly have foretold a photograph, to say nothing of moving pictures.

Each set of facts as they come under notice are accepted without prejudice as having their legitimate place in the nature of the world. Neither the chemist nor the physicist attempts in the first instance to " explain " the events of one order in terms of the lower order. Each attempts to discover the constants and uniformities of the phenomena as given in his own field. Thus, the chemist analyzes matter into elementary substances, and conceives these to consist of uniform " atoms." He studies the atoms, qualitatively and quantitatively, and discovers among other things that almost any two kinds of atoms can form a new substance or compound. He studies the qualities of these compounds again without prejudice: that is to say, he does not introduce any *a priori* dogma as to what these new compounds *ought* to do, how they *ought* to behave, what prop-

erties they *ought* to have. As a matter of fact he has no way of knowing, in advance, what the properties of a compound would be. The classical case of common water illustrates this.

Emergence

There is absolutely nothing in the behavior of oxygen or that of hydrogen which would enable one to predict the qualities of the compound, hydrogen oxid or water. Two tasteless, colorless, odorless gases, invisible and intangible, combine with more or less violence and there comes forth a totally different substance — a colorless and tasteless and odorless liquid of very distinct properties. These properties are in no sense the summation of the properties of oxygen and hydrogen. In the language of George Henry Lewes, writing in 1875, the character of water *emerges* from the situation. Water here manifests something new, something that did not exist before, and something which could not be predicted from a knowledge of the constituents, oxygen and hydrogen.

The conception of emergence had been recognized much earlier, but has become in modern times a more and more conscious part of our thinking. We find many kinds of emergence. From every distinct situation there comes forth something other than is implied in the mere addition of the elements. Alloys of metals present such examples — we have new properties in the way of hardness, melting point, "stainlessness," ductility, that are not the mere resultants of addition or subtraction. When a salt is formed from the interaction of an acid and a base, there emerge new qualities that are present in neither member of the combination. The synthetic chemist can make endless combinations of a few atoms of two or three elements. The same proportions of identical elements will yield an endless series of substances with varied properties and values. When the composition of thyroxin, a characteristic product of the thyroid gland,

was determined, scientists proceeded to reproduce it synthetically. Hundreds of compounds were produced having the same composition — but not the same constitution. A slight difference in the arrangement of the same atoms meant an important difference in the behavior of the compound. In advance of finding out neither Crookes nor Röntgen could tell that "X-rays" would emerge from the electrified vacuum tube: there were phenomena absolutely new and unpredictable, emergents in distinction from resultants.

The aggregation of units of a given order brings about the emergence of something new; and this something new is of a different order. Thus molecules are the outcome of the chemical combination of atoms; there emerges in the process a new set of qualities, and the product is of a different order from that of the constituents. A collection of say four to five points forms a pattern that is different from any to be found in the single points themselves; and this pattern besides being something "new" is also of a different order. A given mixture of oxygen and coal dust is explosive, but it is futile to search for the "explosiveness" in either member of the combination — it is something new and emerges from the interrelations of the two. The wires and iron parts that are assembled into an electrical generator constitute a new whole which has properties that transcend the sum of what the separate elements manifest.

Orders of Reality and of Law

The scientist may confine himself to studying what happens in a given order of aggregates or bodies and he may succeed in discovering "laws" that obtain uniformly for such beings. He may therefore interpret processes and events on a given level, without regard to what happens elsewhere. The economist, for example, does not need to take into account the laws of celestial mechanics, or of hydrodynamics. Yet he may have to take into account laws of psychology, that is, the uniformities observed among bodies

which enter into the economist's aggregate — human beings in this case. Indeed, we should have here an example of "explaining" in a strictly mechanistic way, *if* the economist could actually account for economic phenomena and predict entirely in terms of his understanding of human behavior — that is, the behavior of human individuals in various situations.

The notion of emergence helps us to understand the appearance of novelties in the universe, without offending our bias toward uniformity. It enables us to accept the appearance of the new by discontinuous jumps without implying the miraculous. It makes unnecessary the intervention of a creative act in the cruder sense — that of making something out of nothing, or that of irresponsible infraction of the order of the universe. The emergent, however unexpected or unpredictable, is conceived as a shift of action onto a different level, or into a new direction, the establishment of new kinds of relationships. In this sense, then, we may interpret many of our problems that seem to call for special essences or principles that are not "mechanistic."

There are numerous apparent breaks among the various orders of reality — from elements to compounds, from non-living to living, from physiological processes to mentality, from organic to social, and so on. These abrupt breaks are not to be considered as miracles. Nor is it necessary to call upon special acts of creation to account for them, even though we may not be able, for the present, to explain them in simpler terms. We have already learned to accept the principle of uniformity in each of several separate fields. But the laws of one order seem to be transcended by the processes in another order. The physicist cannot account for the properties of compounds from his knowledge of elementary substances; nor can he account for organic processes from a knowledge of physico-chemical principles. Because the facts themselves are familiar enough, however, he does not feel called upon to assume a Chemism or a Salinity as an active principle to explain what happens. Nor does

he consider the phenomena as beyond uniform law, or as miracles.

In the same way we find that carbon compounds behave in protoplasm as they do in test-tubes, with something new intervening. The uniformities in organism transcend the laws of physics and chemistry, yet without violating them. We find that in stimulus and response matter and energy behave as they do in artificial, lifeless systems, but that something new appears which is not present in the latter. The uniformities in the nervous system transcend the laws of lifeless matter and energy but do not contradict them. It is by the same token unnecessary to invoke a principle that reaches beyond orderly cause-and-effect action.

If then we accept the principle of uniform causation, that is all that the "mechanistic" explanations need imply — the establishment of working principles of cause and effect at any level, or in regard to any order of being. If we were as sure of the "law of supply and demand" as we are of the "law of multiple proportion" in chemistry, or of the "law of hybrid segregation" in biology, we could deal with certain economic processes mechanistically, and we could explain certain social phenomena mechanistically. Similarly in psychology, many of the "laws" are at best approximations to sound generalizations. In so far, however, as they are sound we can apply them in a strictly uniformitarian manner to the explanation of phenomena: and we should not in that case have to apologize for assuming or for ignoring the "soul."

Emergence and Missing Links

The concept of emergence accords recognition to different orders of being, each with its own peculiarities of structure and behavior, with its own uniformities or laws. This concept thus enables us to think of the sequence of events as *evolutionary* in the scientific sense of orderly and uniformitarian. It enables us also to think of the sequence of

events as *creative*, in relation to the many novelties that life has presented, and particularly in relation to the transcendent nature of different classes of phenomena. It makes possible a reconsideration of many of the age-long problems from a fresh point of view. Especially helpful is it in connection with certain problems that have presented themselves in the form of mutually exclusive alternatives about which we could never come to any conclusion — mechanism as against vitalism is only one of these. There are also materialism against idealism or spiritualism, determinism against freedom, naturalism against supernaturalism. And perhaps "heredity versus environment" is but another of these apparent contradictions upon which the concept of emergence will help us throw some light.

It is possible further that "emergence" will facilitate the clearing up of a great deal of confusion about "missing links." Any evolutionary point of view must recognize many sharp breaks and assimilate them into an orderly scheme of thought. These breaks need not represent intermediary stages in development, as we had been taught to think, but particular situations, nodal points, out of which emerged unpredictable departures, or divergences from the previous line of development. Adventitious buds appear upon the stem of a plant at unpredictable points: yet nobody looks upon them as miracles, or as intrusions upon the laws of growth. We think of them rather as the normal events in certain, but to us unknown, situations. In the same way we look upon the reaction between an animal and its bacterial parasites as normal, in the sense of conforming to general causo-mechanical principles, even though we cannot anticipate an infection or predict in detail the course of a disease. It is sufficient that from a certain juxtaposition of host and parasite certain phenomena will emerge, which neither member of the combinations shows by itself.

So we may conceive life as emerging, in the course of time, from a certain combination of non-living matter, as certain compounds with their peculiar properties emerged

from simpler matter. And so, with each aggregation of living stuff new properties and relationships emerged, making possible still more complex emergences later.

We do not know anything of the nature of the "gene" or determining factor in the chromosome. We know only that each such hypothetical factor does in fact influence the development of various structures in the organism; and we know that some body characters manifest themselves only as two or more such factors are present. We may therefore conceive the character *as developed* to be an emergence from the interaction of the two or more factors. We have seen that novelties sometimes arise in plants and animals through the coming together of different factors from the two ancestral lines. We may go farther and assume that a mutation may arise as a result of the modification of one or more factors. It is not then to be supposed that a new character is necessarily the direct result of a modification of a factor. It may be that a new character *emerges* from the new interaction, from the adventitious coming together of two or more factors that were never before present together.

The factorial hypothesis does not tell us anything about the nature, structure or source of the factors. It assumes that from the coming together of a and b there emerges somehow a result that is different from a mere summation of the doings of a and b.

Whether the large brain of primitive man arose as a single mutation, or whether it is an indication of orthogenetic tendencies, it may not be necessary to find as "missing links" a complete series of intergrading forms with "hardly perceptible differences" separating them. It should be sufficient to find indications or relics of types from which primitive man could conceivably have emerged. Indeed, it has been seriously suggested that the overgrowth of the forebrain in man, with all the consequences which that has entailed, is analogous to the overgrowth of horns, teeth and plates in now extinct forms; and that it may become the cause of the

decline of the human race, as overspecializations in the past were the undoing of their possessors.

Dependency

Much of the difficulty which we experience in assimilating evolution to our habitual way of thinking comes from our failure to recognize the various orders of aggregation and the various " laws " which operate. Too often we attempt to " explain " all experiences with a limited set of laws or principles. Those who start out, for whatever reason, with the assumption that explanations are to be in terms of the end or purpose, find offensive the mechanistic approach. Everybody recognizes that all events are contingent, everything that happens *depends upon* something else; but the direction in which one seeks for the significant contingencies will determine his conclusions. Various attempts to understand the processes in living things will illustrate this.

In one sense the happenings in a living cell are dependent upon the chemical composition of the proteins, fats, sugars and salts that are present, and upon the temperature, the humidity, the illumination and other environmental factors. We cannot say that a given salt or a given proportion of water " causes " one or another thing to happen. We can say with some assurance that the total happening is in some profound way the outcome of the total situation, considered in purely physical and chemical terms. On the other hand, it would be just as true to say that the behavior in a given cell is dependent upon the nature or constitution of the whole organism. The water and salts and fats and sugar in the cell of a dog's muscle are identical, so far as the chemist and physicist can find out, with water and salts and fat and sugar in the cell of a human brain. Molecule for molecule they would behave in exactly the same way in a test-tube. In many respects they behave the same way in their respective natural surroundings. In other respects, however, we have reason to feel sure, the conduct of these materials is

influenced not merely by the physical and chemical elements which we may isolate from their respective environments. It is influenced also by the whole system of relationships which comes from their being *integral parts of different systems* — of dog muscle in one case and of man brain in the other.

Even on a simpler scheme of organization we find this to hold. A given current of electricity going through a mile of copper wire of a certain thickness is somehow influenced by the straightness or curvature of the wire. As matter becomes integrated into molecules, organisms, communities, the processes at each level, while made possible by those at a lower or underlying level, come in a sense to dominate those lower ones. In this sense it is conceivable that protoplasm regiments non-living matter into its own form. The process of assimilation is looked upon by the scientist as a physico-chemical process. It nevertheless depends upon the structure and properties of the protoplasm which is assimilating as truly as it does upon the structure and properties of the nutrient materials which are being assimilated.

Biologists long ago recognized that in the development of a plant or animal from the egg, it is just as true to say that *the organism divides itself into cells* as it is to say that the many *cells* (formed by successive division) *combine to form an organism.* The nature of the tissues and organs depends upon the way the cells divide and differentiate, but the dividing and differentiating of the cells depend upon the kind of organism of which the cells are parts.

From this point of view it is further conceivable that the higher levels of sensation and mentality emerge out of organic synthesis, and that in turn consciousness commands or determines the organic reactions. The physiologist says that the reaction of the organism *depends upon* the physico-chemical state of its tissues and juices, and upon the physico-chemical state of the environment. This is true. But it is also true that progressively the higher commands the lower,

which *depends upon* the higher in a somewhat different sense from that employed by the chemist. It is then in this new sense, clarified by a consideration of new qualities as emergent, that mind is conceived by some philosophers to control the material.

Nothing But

Another difficulty, shared by the mechanist with his opponent, is the frequent disregard of the fact that an aggregate may manifest something more than the sum of its parts. We find, for example, a specialist like the late Jacques Loeb, denounced as "materialist" because, having described an intricate organic process in physico-chemical terms, he is supposed to see in life "nothing but" atoms and molecules and electric charges. On the other hand, we find a man like Ernst Haeckel, keenly aware that he and his kind at least are capable of high-grade thinking and lofty sentiments, assuming that whatever is in the whole must be in the parts; and concluding therefore that every last atom of matter must bear its fragment of the soul of the universe. Whatever that may mean, and regardless of whether it is "true" or not, the point is that while the logic is perfect, the assumption is unwarranted, or at least gratuitous. While in a strict mathematical sense nothing can come out of a combination that did not go into it, we know that new qualities do emerge from every aggregate, every recombination of parts.

Because of the frequent disregard of this principle, we observe the tendency for some thinkers to push a given rule or generalization beyond all legitimate bounds. The mechanist may thus go too far when he insists that since the balance and the test-tube can demonstrate the organism to be made up of so and so much carbon, hydrogen, nitrogen, and so on, whether alive or dead, the living being is "nothing but" so much matter. Yet everybody knows that the organism dead is somehow different from the organism living,

however confident we are in the balance and the test-tube, however uncongenial we may find the assumption of an imponderable "vitality." In the same way, as we have seen in the case of Haeckel, one may push the explanation from purpose or spirit too far in the opposite direction. I can convince myself that I know what I know only because of some processes in my immaterial mind; but that is far from demonstrating that all knowable exists only "in the mind" or consists of "nothing but" mind.

The difference between a well executed sculpture and a block of marble of the same mass is not to be described in physico-chemical terms. It is not necessary for the mechanist to save his intellectual pride by declaring that the sculpture is "nothing but" marble. So long, however, as the scientist continues to analyze intricate organic processes by following his mechanistic methods, we have no right to disparage his results for fear that he may reduce our soul to "nothing but" matter.

Creative Synthesis

The founder of modern experimental physiology, Claude Bernard, has been again and again roundly denounced as a "materialist" because he insisted upon carrying the methods of the physical and chemical laboratories over to the study of living processes. Nevertheless he also insisted in all of his teaching that the value of any analysis is limited by the fact that the elements, when separated from the whole, have different relations. However much we may learn from the parts, the whole can only be understood as a whole. In his *Introduction à la Médecine Expérimentale*, first published in 1865, he writes:

> "In chemistry, synthesis produces, weight for weight, the same body made up of identical elements combined in the same proportions; but in the case of analyzing and synthesizing the properties of bodies, *i.e.* synthesizing phenomena, it is much harder. Indeed, the properties of bodies result not merely from the nature and proportions of matter, but

also from the arrangement of matter. Moreover, as we know, it happens that properties, which appear and disappear in synthesis and analysis, cannot be considered as simple addition or pure subtraction of properties of the constituent bodies. Thus, for example, the properties of oxygen and hydrogen do not account for the properties of water, which result, nevertheless, from combining them

"I do not intend to go into those difficult yet fundamental problems about the relative properties of combined or combining bodies; they will find their proper place elsewhere I shall here only repeat that phenomena merely express the relations of bodies, whence it follows that, by dissociating the parts of a whole, we must make phenomena cease, if only because we destroy the relations. It follows, also, in physiology that analysis, which teaches us the properties of isolated elementary parts, can never give us more than a most incomplete ideal synthesis; just as knowing a solitary man would not bring us knowledge of all the institutions which result from man's association, and which can reveal themselves only through social life. In a word, when we unite physiological elements, properties appear which were imperceptible in the separate elements. We must therefore always proceed experimentally in vital synthesis, because quite characteristic phenomena may result from more and more complex union or association of organized elements. All this proves that these elements, though distinct and self-dependent, do not therefore play the part of simple associates; their union expresses more than addition of their separate properties. I am persuaded that the obstacles surrounding the experimental study of psychological phenomena are largely due to difficulties of this kind; for despite their marvelous character and the delicacy of their manifestations, I find it impossible not to include cerebral phenomena, like all other phenomena of living bodies, in the laws of scientfic determinatism." [1]

Emergence and Variability

The child alone is a different being from the child in school, or in his own gang, or among strangers: in each situation there emerges something distinctive. Every person has had the experience of feeling himself affected in distinct ways by various other persons. It is not merely that each

[1] From translation by H. C. Greene, *Introduction to the Study of Experimental Medicine* (pp 90–91), New York, 1927.

person stimulates you or inhibits you in a distinct way. You yourself affect each of the others in a distinct way; and from the meeting of any two there must emerge a unique quality.

We can perhaps look upon organic variability itself as due to emergence. The individual starts, as we have seen, as a fertilized egg. The germ cells themselves resulted from repeated cell-division, accompanied by increase in mass through assimilation of foreign matter. Even if the cell-divisions are quite uniform and precise, the fact of growth introduces variables at every stage. There are qualitative and quantitative differences in the nutrients available. The situation of each succeeding cell differs from that of every other, with relation to heat or moisture or chemical factors in the environment, and so on. After the fertilization, it is almost inconceivable that the development should proceed with all the conditions for every individual absolutely identical at every stage and for every detail of structure. Variability is thus unavoidable, involved in the very fact of organization and complexity.

The way of life entails assimilation under a variety of circumstances, and so variation in the course of development. The same principle may be conceived to apply to the progressive multiplication of germ cells, although, as compared to body cells, these are relatively well protected. We have not been able through experimental methods, as by change of temperature, salinity, etc., to bring about consistently fundamental changes in germ cells. There are nevertheless indications that external conditions do influence the behavior of the chromosomes; and Muller has succeeded in obtaining relatively large numbers of mutations in Drosophila through graded doses of radium emanations (page 164).

Lamarck assumed that the tendency to vary toward greater complexity is inherent in the nature of living matter, and accepted this as a final fact, without attempting to seek its cause. It is given with life, and thus to be treated as a datum. It may be that Lamarck was right in this, and that

it is futile for us to try to find the cause of this "tendency," just as it is hopeless, at a certain stage of chemical science, to seek for the cause of "chemical affinity" between two given elements, or the reason for the different atomic weights.

Protoplasmic Predisposition

Many biologists have suggested the search for the mechanism of evolution in the very nature of protoplasm itself. In the last decade of the Nineteenth Century a German biologist, Georg Pfeffer, extended his criticisms of the theory of natural selection to emphasize the doctrine that *living matter is self-directing and self-propelling*. These two properties include the capacity for automatic variability in adaptive directions. This was intended not as a mystic surrender of the problem to vitalistic interpretation, but as an affirmation of fundamental data for the biologist. Living matter has indeed the capacity to assimilate to itself non-living physico-chemical systems and to direct or control physico-chemical processes to serve its own ends. Living matter has a physico-chemical aspect, but it has also a conscious or purpose-serving aspect. The connection between the two is unknown, and perhaps beyond our reach; but both aspects must be subjected to scientific study.

We can at any rate accept the fact that living matter does actually form progressively more complex aggregates. There are single-celled plants and animals of many degrees of complexity, and there are forms of colonial type, in which there is aggregation but little or no differentiation or division of labor. Among the algæ and fungi there is already a division in the aggregates of almost identical cells, between the reproductive and the vegetative groups; and among the vegetative cells, there is a division between the mechanical tissues and the food makers. Similarly among animals, we can see many grades of aggregation with corresponding degrees of differentiation, from the sponges up to the highest. And at each level of aggregation we find emerging charac-

teristic types and degrees of integration and differentiation, until we come to the highest orders of intelligence in man and his nearest relatives.

Emergent Evolution

The doctrine of emergent evolution has become disseminated in recent times largely through the teachings of C. Lloyd Morgan, a disciple of Huxley's, who laid the foundations of comparative psychology. Morgan frankly recognizes that he is dealing with philosophical problems quite as much as with purely scientific ones. Perhaps his chief contribution lies in clearing much of our specialized terminology of its arbitrary and restrictive connotations, and in helping toward a more effective formulation of our problems and issues.

This theory does not pretend to tell us at present just how each level or order of being comes to emerge from a special aggregate of a lower order. It merely calls attention to the fact that in our daily experience we may observe emergence to take place, and invites us to reconsider our principles and issues in the light of the implications of such facts. Especially valuable is this approach in reconciling contending interpretations, not in the sense of neutralizing them, but in the sense of suggesting new bases of agreement. This is, to be sure, no new thing in the history of thought; it is in this respect essentially a form of transcendentalism. It comes, however, from one who has been thoroughly disciplined in the "mechanistic" science of the Nineteenth Century and who is fully appreciative of what it has to offer, but who at the same time realizes that where opinions differ it does not follow that one party is right and the other wrong, one who is in full sympathy with the purpose of philosophical study.

From the point of view of emergent evolution it becomes possible to extend the scientific method of research to the more complicated problems of psychology and the social

studies, in the material of which progressive integration and differentiation are quite as obvious as they are in the evolution of living plants and animals; and perhaps to extend the philosophical method more effectively to the consideration of the field in which physico-chemical methods have hitherto prevailed.

Summary

Masses of facts have been accumulated about the living inhabitants of the earth, those of our own times and those of ancient times. About these facts there can be no dispute, they are open to all who have eyes to see. These facts leave no doubt that "evolution" has taken place, that is, that there has been continuity of descent with more or less rapid modification of the forms, among animals and among plants. This conclusion is supported by outstanding facts of structure, of classification, of physiological characteristics and processes, of distribution of forms in time, of distribution of plants and animals on the face of the earth at the present time, of development, of heredity.

The processes in detail, or the mechanisms that have brought about modification of types in the course of descent, are not altogether clear. Several theories are logical enough in general terms, but are not in agreement with the details of fact. Certainly no one theory of evolution adequately meets all the facts.

There has been variation, variation is constantly to be observed among all living forms. This variation is indeterminate, that is, it takes place in all directions, with respect to every character. On the other hand, there is unmistakable evidence of determinate or directed evolution. These two sets of facts, however, are not mutually contradictory, since the two kinds of variation may arise from totally different sources.

Directed variation, or orthogenetic evolution, has in many cases led to "improvements" or to better adaptation

of a species; but it has also led to excessive specialization to the point of handicapping individuals and species. We have no satisfactory theory to explain orthogenetic variation, except the assumption of an "inherent tendency," of something in the nature of living matter. This assumption need not be in the form of a mystic dismissal of a scientific problem: it may be an objective, although tentative, description of living matter as having, among others, the property or tendency of developing along such and such lines.

The attempt to explain what happens in the living world runs into the existence of many orders or levels of reality, so related to one another that, while happenings in one level are contingent upon events in another, we have no way of knowing just what the connection is. We can work out satisfactory laws of causo-mechanic relationship within a given order, but cannot transfer these laws to a different order. The idea of emergence helps to bridge these gaps, at least formally. It helps us to search for causo-mechanical principles in living beings without waiting to build up a complete system of knowledge covering the entire universe, from the electron to the soul of man in society. It helps us to accept the appearance of new qualities, new kinds of phenomena, without resorting to miracles and magic. It helps us to conceive of evolution as an orderly process without insisting upon absolute continuity or upon "missing links." A better understanding of the actual workings of living bodies makes possible our reliance upon general laws or uniformity and at the same time our recognition of constant change as inherent in life.

THE PRACTICAL SIGNIFICANCE OF EVOLUTION

Chapter 14

Living in a World of Change

WHAT has the idea of evolution done to the common thought? We should glance first at the prevailing outlook in the middle ages and earlier. During these periods the world appeared to most people as a place of inscrutable mystery and fear. For most people the world was run by a multitude of imps and goblins, capricious and irresponsible, petty and jealous, influenced by the trivialities that loom large in the mind of a simple child.

Most of the inhabitants of this country and of European countries today have perhaps grown beyond that level of "belief." By the end of the Fifteenth Century Europe was made up of Christian countries, in which official religions prescribed a theory of the world and of its workings. Technically, these official religions were monotheistic. That is, they presupposed a single controlling deity as the source of the universe and of its destiny. In practice there was still a great deal of polytheism. That is, large numbers of the populace continued to fear a multitude of mysterious forces, and to seek personal help from several supernatural powers. And these powers were for the most part conceived as persons, not merely metaphorical personifications.

Toward Order

We like to contrast our outlook and insight with the absurdities that filled the minds of our ancestors. That yields the satisfaction of intimating a certain superiority on our part. The superstitions of the ancients, however, mean hardly more than ignorance — a lack of such special knowl-

edge as we may have today by good fortune, not by any merit of our own. With the same background we should probably be no whit less absurd. What would we ourselves do if we had been brought up in a world operated by one or a few agencies having the ordinary characteristics of ordinary human beings, plus the divine attributes of omniscience and omnipotence? What is implied for most people today by the identification of personality in the deity with susceptibility to ordinary human motives? What is implied, for most people, by the identification of omnipotence with liberty, and of liberty with irresponsibility?

If we thought of the invisible "forces" as more or less independent personalities, we should naturally attempt to enter into negotiations with them for favors, or at least for the avoidance of disfavors. We should implore or propitiate, we should bargain or threaten. We should attempt to play one off against the other. Is not this the picture we get of certain "heathen" procedures? The heroes of Homer and the ordinary folks that made up his mobs behaved in relation to their gods precisely on such assumptions. Roughly speaking, this was the common state of mind in Europe until the Elizabethan period, the age not only of Shakespeare and Jonson but of Bacon and Gilbert.

Many things happened to change the appearance of the world from this period onward. More and more the growth and diffusion of science have forced a change in prevailing attitudes, although for most people the world has not yet come to look like one of law and order. Most people no longer think of a special demon in the volcano and another one in the storm. They are confident that the outcome of pushing familiar buttons, of pulling familiar levers, of turning familiar knobs, will be uniform and for the most part predictable. When things go wrong, they know how to blame a leaky pipe or a crossed wire, instead of the personal aggrievement of some deity.

A world of ghosts is different from a world of impersonal forces. The ghosts may be restless spirits, but they

have their limited aspirations and capacities (being, by hypothesis, man-like personalities). Their activities and their interactions must leave the world substantially unchanged, a stage for the coming and going of human puppets. A world of impersonal forces, on the other hand, even if conceived as a "mechanism," makes every day a new beginning; at least, the vindictiveness and the envies of the gods do not carry over. Above all, it makes possible for man a new hope that in his day by day struggle he may yet attain the upper hand.

While most people are not scientists, or even scientific, they do more and more assume that they are living in a world of impersonal forces that can be captured, understood and controlled. The contrast between this view, in so far as it permeates a whole population, and the older view constitutes a revolution. And the general concept of evolution, as a way of looking at the world, is an inevitable consequence of the coming of science.

In considering the effects of evolution, as a way of looking at things that has become increasingly prevalent in two generations, we must guard against reasoning on the simple formula, *after therefore because*. Not everything that has happened since the publication of Darwin's *Origin of Species* or since the Civil War is a result of that event. There have been far-reaching industrial and social and political changes during this period, and it would be difficult to say what part any purely intellectual achievement may have played in these developments. There are nevertheless pretty clear evidences that evolutionary thinking has been gaining ground and that it has had marked influences in practical affairs as well as in purely academic circles.

Comparative Studies

The *comparative* method of study which is frequently associated with evolutionary thought had already gained ground before the middle of the last century. We have

noted that Georges Cuvier elaborated comparative anatomy into a powerful instrument of research, although the beginnings of this study were worked out rather crudely in the middle of the Sixteenth Century by Pierre Belon (see page 78). Comparative embryology was similarly established in the early part of the last century by Carl von Baer (see page 132). The study of forms with a view to a better system of classification is itself a comparative study; and great strides had been made from the time of Linnæus to the time of Lamarck. And morphology, also a distinctly comparative approach, received a strong impetus from the nature philosophers at the end of the Eighteenth Century. The objective study of physiology according to the methods of the physical and chemical laboratories was well under way before Darwin's work was presented to the scientific world.

Indeed, we may attribute a considerable measure of Darwin's success to the earlier comparative studies. For these first supplied Darwin a large part of the factual material which he needed for the working out of his theory, and then prepared the minds of his contemporaries for an understanding and sympathetic reception of his theories.

Genetic Studies

The immediate effect upon the biological sciences was to stimulate research in a dozen fields, both among those who sought to find supporting evidence for the brilliant theory, and among those who were either hostile or critical. This increased activity yielded a great body of facts, helped to formulate new problems, and cultivated a point of view which gradually affected research in other departments of thought. This was the so-called *genetic* study of all sorts of problems. Instead of attacking the material of study from the point of view of special problems, it became fashionable to formulate the investigations in terms of evolution: How does this or that come to be?

In psychology, the comparative method became the genetic method when students started out with the presupposition that the material to be compared had to be arranged in the order of transition from the simple to the complex. This meant comparison of the activities of primitive peoples at all levels of culture, the comparison of responses to stimulation in animals at all levels of development, the comparison of child behavior at infancy with behavior at every other age level and so on. The questions uppermost were, How did mentality arise? How did the various senses develop? How does the complex conduct of man in modern society grow out of simpler forms of conduct? In the same way the social studies became more and more genetic.

It should be recognized, however, that even these genetic methods are not altogether new since the advent of evolutionism. They are in fact essentially historical and as such had been pursued in past ages. Rousseau's essay on the social contract is a genetic study of how human relations in society have come to be. Robinson Crusoe has been repeatedly employed as a basis for the genetic study of economic relations. Utopias in the past have frequently taken the form of showing how, from the assumed beginnings in Eden, or from a stranded family, a more perfect society might have evolved. It is true, of course, that these imaginary constructions differed from modern scientific studies in the genetic form in that they dealt with purely speculative material.

Concrete Studies

A third characteristic of modern science is its insistence upon the *concrete*. It is recognized that speculation and theorizing are necessary. Hypotheses have to be formulated, and the many gaps in our knowledge have to be bridged first of all by the imagination. But it is further recognized that inferences have to be verified, that guesses have to be held in suspense, that hypotheses have to be tested out. The imagination can indeed construct many bridges between the

supposed past and the observed present, in every department of thought. It is a different matter, and the special task of science, to find out whether, in the first place, the supposed past corresponds to actuality and whether, in the second place, the imagined bridge corresponds to historical reality.

Evolution and Progress

The term evolution has come to be applied rather loosely to the whole historic process through which the universe is conceived to have passed. Some writers speak of inorganic evolution, by which they mean the formation of stars and planets from nebular mists — or whatever it was that preceded stars and planets and gave rise to them. We hear also of the evolution of different types of matter from presumably simpler types. The stimulation of intellectual activity by Darwin's work, and especially by the concept of evolution as "one thing leading to another," led to the application of this concept to superorganic processes such as language and social institutions, forms of government, the comparative study of religions, and so on. This use of the term evolution has in turn injected into discussions of the subject a certain implication of betterment.

Historically there have been many improvements in the daily management of our lives. We point to advances made in government and in economic surplusage. There has been a wider distribution of the accumulations of culture, and advance in cleaning up pestholes. This conception of progress in human affairs has in fact furnished a stimulating catchword, with invidious reflections upon its opposite. From the scientific point of view, however, progressive change may be considered without regard to any such implication of betterment. Progressive means in fact no more than continuous, as to direction. Darwin himself pointed out that many of the adaptations which a theory of evolution had to explain were of a retrogressive or degenerative type. Reduced or-

gans of parasites, or the reduced eyes of cave-dwelling animals were obviously no "improvement" in the ordinary sense, however adaptive they may be for the organisms in question. There is no need for assuming that evolution means the emergence of superior individuals from inferior ancestors. This unwarranted identification of evolution with progressive improvement has indeed furnished "arguments" against evolution. Thus one writer, "If whales and seals have descended from four-footed land animals, that is not evolution, that is deterioration."

Such misunderstandings are the unavoidable manifestations of thought-patterns fixed early in life. They are as likely to be found among those arguing on one side as among those upholding the other. A leading paleontologist only a few years ago urged the teaching of evolutionary ideas in schools, "in the real sense of ascent and progress." Of course the other senses are just as "real" and just as worthy of consideration.

If evolution is not synonymous with progress it is still a dynamic concept. It implies constant becoming, constant change. It is necessary to distinguish between the biologist's conclusion from all the evidence that there is this constant change which he calls organic evolution, and the human mind's temptation to transform the broad concept into a philosophy of life. This is a necessary distinction. Whatever misuse the individual may make of his own interpretations and applications of evolution will be invariably charged to the biologist who upholds evolution as *a generalized statement regarding the known facts of life.*

From the observed facts among plants and animals, we may be confident that there is evoluton, that evolution affects the "higher" and competitively nonessential functions as well as those that are vital in the struggle for existence, and that man himself comes within the influence of those forces that bring organic evolution about. In some cases the process leads to more and more highly specialized and more and more complex forms. We may, if we wish, consider this pro-

gressive. Is it not these very processes that have culminated in the emergence not only of the human species, but of those mental phenomena that are distinctive of man? And with the rise of consciousness evolution takes on a new direction that may well be "progressive" in the sense of forward-moving, improving, ascending.

Change without Progress

Many grasp at "evolution" as a philosophy of change because from their experience and reflection they are made to feel that every change cannot but be an improvement. But as a scientific doctrine evolution is here rather cold-blooded. Concretely, there remain first of all evidences of primitive forms of plants and animals that have survived through the ages in the same primitive stages. At every stage of increasing complexity there remain such relics living side by side with much more complex forms. And this is just what we should expect. The observed facts regarding the intricate interrelations of living forms suggest the manifold expansion of living things in all directions and their intrusion into all the inter-spaces left by the others. This means that, from the nature of living matter as an automatically expanding system, there will be large organisms and small ones, fast ones and slow ones, those that thrive in the light and those that thrive in darkness, and so on. Now some forms will necessarily diverge more from their ancestral types than others, and from various stages already attained departures will occur in many new directions — some of them "downward," from a human point of view.

There results from all this, in the second place, an adaptation of living things to a great variety of conditions, some demanding more specialized structures and functions than others. In all of these situations, however, the living things are equally well adapted. The pond snail need not be disparaged because it has not attained the speed of the octopus, or the oyster because in the adult stage it has no speed at all.

The flea is in its way as successful as is the elephant and need not " improve " to hold its own.

Further evolution at any point may produce variants without further elaboration of structures and functions; or it may produce further specialization; or it may produce a regression with adaptation to a relatively simpler or more secure environment. In the history of mankind, also, there are evidences of arrested development, long stretches of stagnation, and even of backsliding.

There is nevertheless the possibility, from a human point of view, of bending the current to our purposes. Man has attained a consciousness of values. He realizes that some things in life are worth more than others. He has also attained a confidence in his own mastery of the world through a growing knowledge of how things work. We are able to consider as object of endeavor the reshaping of the world to serve our purposes. We are able to consider even " race betterment." Thus has the advent of an evolutionary outlook made us face the future somewhat differently. We come to see that although change is the order of nature and of life, there is no special virtue in the new merely because of its novelty. On the other hand, we see that there is no occasion for being always fearful of the new. There are values in the already achieved, which should perhaps be retained; but not merely because they are old and familiar, for that would mean merely because we are too comfortable or too tired to negotiate a change. This general view of evolution as change applies to our dealing with concrete situations and problems, and it applies in the realm of ideas and ideals. It is necessary to examine all things as they come, on their merits, without prejudice and without predilection.

Evolution and Education

The diffusion of the evolutionary viewpoint means the gradual passing of the absolute. In relation to truth, it means an increasing concern with more satisfying methods of pur-

suit and diminishing concern with completion. In relation to education it means that we are gradually eliminating the idea that education is a process which is to be completed in preparation for something to come later. The movement for adult education, which at the moment receives considerable attention from professional educators, is but the emergence of this changed outlook into common consciousness.

Memorization has gradually yielded the center of the school to other tasks. More and more is education concerned with teaching people the effective use of the thinking process as an instrument in the solution of problems. Less and less is education concerned with teaching people what they are to think. Teaching what to remember can mean at best the perpetuation of what has been acquired. It makes no provision for testing or for revaluating. It represents a conservation and corresponds biologically to heredity. The content of education has indeed been frequently spoken of as the social heredity.

Teaching to think must often mean the exposure of hallowed conventions to irreverent dissection. It invites youth to challenge institutions that have already forgotten their own origins and justification. It represents the day by day adjustment of living people to actual conditions as found. It makes for change, though not necessarily for improvement.

Perfection and Ideals

Some people are disposed to dream of perfection as the end of striving or the incentive to effort. To some of these the evolution idea serves as an additional spur. To others, it is an impossible notion since it reduces man to a "machine" or a beast. Both the idea of perfectibility and the idea of evolution, however, deserve to be considered on their own merits, and with some regard for the pertinent facts. Perfection suggests fitness in an absolute degree. From the

biological point of view, however, fitness must always be relative, and always changing. The factors with regard to which a living being is adapted are in flux with relation to one another. No matter how long evolutionary changes continue, there must always remain maladjustments and disharmonies and imperfections. Indeed, new ones must also constantly arise, even where there are improvements and gains. Man's erect posture, for example, brings new strains upon the mesentaries of the abdomen, along with the advantage of freed hands and a forward look. Life itself is a manifold *process of adjustment*. When adjustment is complete — that is, completed — life ceases. Both from the general evolutionary point of view and from the stricter biological point of view, perfection in the abstract sense is inherently contradictory.

Whatever spiritual value may be derived from the concept of perfection is equally available — or offensive — to the evolutionist and to the creationist. That is to say, the contradiction between fact and theory needs to be explained whichever view one takes. It is just as logical to reject a personal God because there is so much misery in the world, which the creator either willed or permitted, as to reject the evolutionary view because we fail to see how it will make for perfection or for idealism. Perhaps one's choice between a finished world and a world in the making is again a matter of temperament.

Mental Evolution

The presentation of Darwin's theory of natural selection in support of the general theory of organic evolution made the latter so plausible that there were immediate attempts to stretch it far beyond Darwin's original intentions. This extension included of course the question of mental evolution, which was implicit in the doctrine of descent when applied to man. Man is obviously different from other animals, even from those assumed, according to the doctrine, to be closest to

him genetically. And the outstanding difference has to do with what we call mental qualities.

What follows from the doctrine so far as concerns the origin of mind? Many people brought up on the biblical account of creation were ready at once to reinterpret that as a poetical generalization. Of these, however, large numbers balked when it came to include mentality in the evolutionary scheme. One reason for this was of course the emphasis which Darwin and his disciples placed upon continuity. It would be necessary to find an unbroken chain of mentalities linking man with the simplest forms. Not only was the knowledge at the time inadequate, but the very thought strained the imagination. The human mind is *qualitatively* different from the mind of the ameba or the turnip. It was inconceivable that it should have arisen by a process of slow increments. On the other hand, many enthusiastic evolutionists accepted the implications in principle and were content to leave to later investigations the establishment of the principle as a fact.

At the present time we need not be troubled by these considerations. Evolution need not mean the gradual transition through imperceptible increments. Variations need no longer be considered merely plus and minus fluctuations. It is still inconceivable that man differs from ameba "only in degree." But today we know there are mutations, and these include qualitatively new characters. From a philosophical point of view, we are able to retain our reliance upon causal continuity and still make allowance for the appearance of novelties, even if we do not understand the "mechanism" of transition. If we think of the mental category as an emergent from specialized living matter under specialized circumstances, we do not of course "explain" the origin of mind. We accept it, for purposes of further study, just as we accept the emergence of alcohol and carbon dioxid from the fermentation of sugar, or the emergence of an electric current from a dry cell — processes that we can control in practice, but not yet "explain."

Beast and Spirit

As to the special doctrine of man's descent from subhuman ancestors, we may look upon the findings of the biologist in two ways:

1. We can say that comparison with other animals is degrading, since it makes man out to be a beast. It is a demoralizing doctrine. It is better to teach that man is a spirit — a fallen angel, perhaps, who may hope to rise again.

2. We may say that comparison with animals shows how we differ from the beast, what there is distinctive and worth cultivating in human beings. That is an inspiring and uplifting doctrine.

People who are brought up to think that man is born in sin, and who find it difficult to maintain consistently a human attitude, may be helped to slide back by the suggestion that after all we are another kind of animal — perhaps "nothing but" an animal. Science, while discrediting the theological sanctions of an earlier tradition, fails to supply them a new positive morality or new sanctions for the conventional.

On the other hand, people who are brought up to think realistically of their powers and their limitations, of their aspirations and their resources, may be helped by the evidence of man's advance to a firmer grip on themselves, to a stronger determination to live a life worthy of human beings.

Whether we like to contemplate man's descent from a relative of the apes or not, there can be neither shame nor glory in the facts, whatever they may be in detail. We need take no credit for having ascended to heights so far above the monkey or the amphioxus. There is indeed no need to identify ourselves with our supposed "ancestors" or to identify our own virtues with the processes that have in fact intervened between the past and the present. Certainly we cannot claim that any of our present aspirations had a part in the past becoming; nor can we reproach the more lowly for not having reached our own pinnacles.

We do not need to contemplate the gap that separates us from the apes, then, except as we learn, from comparative studies, to recognize the essentials, whether of resemblance or of difference. For certain purposes comparisons are more profitably made among wider ranges of types. For other purposes we find it more profitable to compare identical twins. But if a comparative study is to have value it must be without prejudice.

Evolution and Mechanism

For the reasons already given, modern science cannot employ a method that assumes personal entities as a basis of understanding or interpreting observable phenomena. The scientist may not say, however, that there is no controlling purpose in the universe. All he can say is that it does not help him to make the assumption, if he is to pursue further the problem of how things work. The assumption of a controlling purpose, or of a consciousness inside the mechanism which he is studying, may be satisfactory for those who do not care to search further; but for the scientist it is no solution at all; it is not even the beginning of a search. He feels that to say the blood distributes oxygen to the tissues because it is its nature to do that, cheats him of a chance to find out what particular connection there is between the structure and the function.

The scientist therefore insists upon the study of mechanism as a method of thought which embraces man and other living things, and which applies to mental processes as well as to chemical and physical. But this search for mechanism has no relation whatever, either scientific or philosophical, to "materialism" as this expression of reproach is commonly used as somehow implying beastliness, or satisfaction in the gross and sensual. Of all the discourses I ever heard the most "materialistic," in this properly disparaged sense, came from the mouth of a bishop of a certain Christian sect. The bishop was celebrating Easter Sunday by elaborating on the

theme, "In the flesh shall I see God." And never was there a more fleshly anticipation of all the lusts. It is not necessary to protest that this is neither typical of "religious" ideas and feelings in general, nor specifically characteristic of a particular sect. We may accept that without argument. It is well, however, for those to whom "true religion" means "our kind of religion" to consider for a moment: (1) that materialism as a scheme of life values is quite prevalent among true believers of all sorts; (2) that there have been not only decent citizens but rather high-minded and spiritually disposed individuals both among professional scientists and among heretics of all sorts. Materialism, in short, is for all practical purposes reduced to a cussword and might better be avoided by all who have serious intentions in the premises.

Today we all are mechanists when we think of our daily work, or of skill in our leisure pursuits. A golf-player or a piano-player would not consider for a moment the substitution of magic words for well-directed pushes and pulls. Nor would we be satisfied to ascribe the successful performances of others to the intervention of invisible spirits. We nevertheless consider ourselves perfectly *free* agents and resent the suggestion that our own behavior is somehow *determined*. This is a materialistic thought and unworthy of the spiritual nature of man. Yet there is no essential difference here between the position of the scientist and that of the person who is sensitive lest his spiritual essence be slighted. The difficulty is that we prefer to draw a sharp line between two orders of mechanism. When the scientist speaks of the mechanism of human conduct we prefer to think that he means pulls and pushes, waves and rays, projections and obstructions. But in our own constant endeavors to influence the conduct of other people we rely also upon — mechanisms, although we do not like to call them that. Of course we do not use levers and windlasses, but we do use suggestion and suasion, exhortation and promise, flattery and threat.

We are confident of our independence in molding our own destinies, in shaping our own course of conduct, in making choices and decisions on principle, or on judicious weighing of evidence. We are just as confident, however, that other people, high and low, are swayed by considerations and influences that, to some degree at least, come from without. We intimate, therefore, that there have been many inquiries for this corner lot, in order to accelerate a sale. Or we intimate that we have another purchase in view, in order to obtain more favorable terms. More crudely, we promise prosperity or heaven, we threaten calamity or hell, to swing the "free" choice of others at election time. In other words, we depend upon mechanisms just to the extent that we become skillful in using them. We "believe in" uniformities on the level of mental phenomena, as against mysterious uncaused processes and incalculable forces, in so far as we have direct knowledge of how human thought and action really work.

Response to Evolutionism

The presentation of the doctrine of evolution (as indeed of every important idea) calls forth two diametrically opposed sets of reactions from different groups of people. Nor are the reactions at either pole consistent with each other. There is the ready acceptance of evolution and its immediate application in support or justification of previously held views, or in the promotion of specific purposes. It is so convenient to be able to say, "Science tells us" that our favorite food fad, or our political theories, or our own brand of social reform is in tune with the infinite. In all cases the harmony thus established is quite plausible and logical. We begin to doubt only when we find the same "science" telling so many things that mutually contradict one another. The immediate resistance to the doctrine is similarly influenced by our preconceptions. Evolution is rejected because it discredits what we have already held — that is, because it belittles our intelligence or our knowledge. And

it is rejected because it implies — to some of us — objectionable inferences and conclusions.

We have already seen that the desire for change in the hope of improvement and opposition to change in the fear of disturbance are operative with many classes of people. With these evolution is accepted or rejected, not on the basis of a well considered examination of the relevant facts, but entirely in terms of hopes or fears. Perhaps most of us are influenced by such subtle factors without being aware of them. A few further illustrations of the rationalizing reception given to the idea of evolution will help to clarify the confusions that have accompanied the discussion for seventy years.

Natural Selection and Social Doctrine

Although Darwin was not interested in economic aspects of human affairs, he seems nevertheless to have been influenced by the prevailing social and economic thoughts of his time. The economic struggle was to him extremely distasteful — that is, in prospect as a student, for he really never took part in it. When he learned that his father's estate would probably leave him enough to insure "bread and cheese" he promptly abandoned his medical studies and resolved to become a naturalist. The concept of the struggle for existence as developed by Darwin seems to have absorbed quite as much from the current social conflicts as from the direct observation of nature. Certainly the botanist in Darwin would not have been impressed with the competitive aspects of life.

With all the qualifications which Darwin himself placed upon the description of the "struggle," it was inevitable that his doctrine should be seized by those who were interested in sanctifying the commercial competitions that characterized so large a part of the Nineteenth Century. Exploiters of the helpless were not long to discover that atheistic science furnished a sanction for taking advantage of other

people in bargaining for wage or for prices. On the other hand, the rebellious spirits of the submerged portions of the population found also a justification in "science" for the doctrine that all is fair in war. In addition to citing scripture as needed, debaters were enabled to cite science.

"The struggle for existence" and natural selection serve to support both the teachings of extreme militarists and extreme pacifists, to take a single striking illustration. The philosophy of struggle as the means by which the superman is to arrive becomes a justification, in the name of science of the most ruthless and brutal attitudes. On the other hand, the fact that in war the soundest and the bravest individuals are the first to be slaughtered is used to point the deteriorating effects of war upon the human race: it is only the relatively unfit who are left by war to perpetuate the race and there must therefore be progressive degeneration in proportion as we resort to war to settle our international differences. We have seen that similar arguments were used by Haeckel and Virchow, not on the common assumption of the Darwinian formula, but for and against Darwinism respectively, on the common assumption that the menace of Socialism must be suppressed.

It would be interesting to inquire how far Karl Marx's theory of the class struggle was formulated under the influence of the same circumstances. At any rate, the common thought of the middle of the century took readily to the idea of competitive struggle as the normal course of nature and of life. It was futile subsequently for Darwin or for any of his defenders to insist that the struggle for existence was not intended to picture nature as "red in tooth and claw" or to sanction the atrocities in human competitions as according with the laws of nature.

Mutual Aid

The implied cruelty of nature, which the doctrine of natural selection emphasized, made the Darwinian teaching

offensive to many people. As was to be expected, many objected on the ground that the cruelty of nature could not be reconciled with God's goodness or with the Christian counsel of kindness and forbearance. Many others, who were quite ready to accept the general theory of evolution, were estranged by the implied justification of brutality and selfishness as the essentials of "success" in life.

Naturalists as well as students of society had already noted the remarkable development of mutual aid, coöperation and social living among certain insects, among birds and among mammals. Certainly the members of a beehive are not in competition with one another. On the contrary, the exertions of the individual are obviously calculated to help the whole community. Similarly, the members of a flock of geese, or a pack of wolves, or a herd of wild cattle, or a rookery, are quite as much engaged in promoting the common welfare as they are in securing their individual survival.

These facts could not be overlooked. While they seem to mitigate the supposed glorification of selfishness and cruelty, so far as the natural order of things might carry moral implications, they could be assimilated to the doctrine of natural selection without great difficulty. The evolution of simple forms proceeded from the one-celled to the many-celled, with division of labor and progressive specialization of function. Similarly at higher levels, there was integration of individuals because of advantages gained from division of labor and mutual exchange of services. The evolution of the societal group, in other words, can be understood as the result of natural selection exactly as can the evolution of more and more complex organisms from simpler ancestors. The only difference lies in shifting the incidence of advantage from the individual to the group. Natural selection will eliminate those hives of bees, those colonies of birds, those packs of wolves, in which the individual conducts himself, because of his native constitution, in a manner detrimental to the welfare of the group. The principle of natural selection lends itself as well to the use of a Fiske, who

seeks to reconcile a system of ethics with prevailing science, as it does to the needs of a Nietzsche who seeks to glorify ruthlessness and arrogance.

The argument on both sides can be elaborated indefinitely — and has been. Darwin himself stressed the importance of variation, since he conceived the "struggle for existence" to be effective, in an evolutionary or selective sense, only where there is variation; yet some of the attempts to apply his teachings to political theory assumed a fundamental equalitarianism. It is of course conceivable that a struggle would ensue even among perfectly equal individuals, where there was a deficiency of food or water, for example, or insufficient standing room. The struggle in such case, however, would not be selective and therefore unrelated to evolution.

We may recognize at work here the same processes that had already been observed in other great controversies. Not only can Satan quote scripture, but perfectly sincere exponents of the Bible have used it for justifying slavery, prostitution, the burning of witches, human sacrifice — and others for combating these institutions. If the Bible has been used to discredit the evolutionary doctrine, it has also been used to confirm it. For did not the several races of man diverge from the parental stem and become established as distinct "species" in but a few thousand years?

Evolution and Natural Selection

The confusion between the general theory of organic evolution and Darwinian hypothesis of natural selection is not confined to the general reader. It crops out frequently among professional biologists and other scientists. A recent writer on racial characters passes back and forth between description and inference without seeming to be aware of the difference. "The black skin of the tropical negro," we are told, "protects him from sunburn"; and ". . . the Eskimo has under his skin a layer of fat that serves as a

blanket against the cold of the frozen north." We may accept these statements without much misgiving. The inference of adaptation in the two cases is at least plausible. Presently, however, we pass from such direct inference to far-reaching deduction: "The intelligence and ambition of the European is one of the outcomes of the competition of a life of commerce that arose on a continent that nature adapted for trade with a deeply indented coast line." This is of course logical enough; and if we grant the premises, it may be "true."

There is a return of the anthropomorphic *nature*, which is probably not intended by the writer, but which shows how difficult it is to get rid of habitual forms of expression, and to avoid their implications. And there is the bland assumption of *the* mechanism of evolution as identical with natural selection, metamorphosed into a human instrument of progress and uplift — competition, no less. Another example of similar confusion is the following: "The great industry of the Chinese arose from the pressure of dense population and the ever present danger of famine." Certainly we can see the value of industry, even perhaps its indispensableness, under the circumstances indicated. We can hardly be sure, however, that the "industry" in question is a directly heritable character in the biological sense; and if it is, that it "arose" from the pressures and dangers as alleged.

These are all examples of confusion from scientific writers and are offered to suggest that it is no simple matter to clarify our thinking on subjects that are so intimately tied up with our earliest impressions and orientations regarding the nature of the world and of its most interesting inhabitant.

Adaptation and Purpose

The rise of the evolutionary idea has brought to the front a clearer recognition of the problem of adaptation.

Each living thing is obviously *fit*. According to the older ways of thinking, each organism, or species rather, has been made fit, in the first instance, by the act of creation; and it had remained fit because of the constancy of the environment. What we now call adaptation and are coming to think of as a never-ending *process* was formerly looked upon as a fixed *condition*, something absolute. The evidence of an underlying design became manifest in the multitude of details that fitted living things to their surroundings and conditions of life, and especially the details that serve man's life and his conscious needs. Even the color of the foliage was related to our own comfort and the special needs of our eyes for a restful outlook.

The mode of thinking which rested upon the assumption of a purposeful making and guiding of things as we find them is not in itself either religious or irreligious. It grows normally out of human experience with the *facts* and furnishes a simple and intelligible interpretation of the remarkable interrelations between plants and animals, between different species of living things, between life and the non-living world, between man and the non-human world. Paley's watch is no more eloquent of design than are the daily happenings in the lives of familiar plants and animals.

Science today dispenses with the notion of purpose in studying structure and behavior, among living things as among galaxies and atoms. But the conception of an overhanging purpose anticipates the teachings of science and anchors itself firmly in the child's mind. The professional scientist who learns to assert his faith in a more objective and impersonal pursuit of truth and to discuss adaptation as a natural phenomenon may yet continue to speak — and indeed to think — in terms of design. It makes his mode of thinking no more and no less religious, and certainly no more scientific, to substitute "nature" for God. Current textbooks in science still reveal frequent lapses into forms of speech that imply assumptions which the authors expressly repudiate.

Purpose in Nature

One writer speaks of the "numberless devices nature has evolved for furthering the success of her children." "It is the fate of a great majority of the creatures to fall victim to other animals to whom they serve as food," he writes. From this we might conclude that nature has concocted many devices by which she assists her favored children in escaping the relentless persecution for which she has so admirably equipped others. Again, "Nature is full of devices by which those who have proved their original endowment by winning out in the struggle shall hand on this endowment to a subsequent generation. In other words, nature is anxious that they shall successfully mate."

In a more ambitious book for advanced students, we are informed that "The extreme care with which the cell mechanism partitions the chromatic material in each successive cell division is in itself an adequate testimony of the fundamental importance of this material." No doubt the chromatic material is very important; but the testimony presented is hardly adequate. The chemist's law of multiple proportions shows quite as much regarding each of the elementary substances. The "extreme care" with which nature attaches to a given quantity of sodium precisely so much chlorine — no more and no less — is adequate testimony of her excellent management, at once generous and frugal! This would be considered nonsense and utterly futile from the point of view of finding out just what happens within the substance of the world.

The habit of personifying the "forces" and "principles" comes early and is broken with difficulty if at all. Now the evolutionary viewpoint has not rid us entirely of this habit. It has, however, made more and more men and women aware of the danger of adhering to the thought forms involving personified entities, where the intention is to find out how things work. It makes us disclaim advance knowledge of God's purpose, or nature's purpose. We find it

more helpful to apply ourselves to a search for relationships that we can understand in terms of "invariable antecedent," or cause-and-effect, in the ordinary common-sense way.

There is another sense, however, in which we may speak of purpose without the same danger of confusing our vision, and without the need of avoiding the concept of mechanism in nature. We may perhaps catch a glimpse of this by recalling the estimable old lady who wondered how it came about that nature had placed the large rivers in the neighborhood of the large towns. As an act of foresight, this juxtaposition is truly marvelous. If, however, we take into account something of the nature of man — his workings, that is — and of the chronology of events, the fact seems commonplace enough. In the same way we may understand other adaptations. We do not need to say that the ocean was made as it is to fit it as a habitation for sponges. It is enough to say that sponges find it possible to live in the ocean, but not in meadows. We do not need to say that the earth was given its texture and composition to fit it for worms. It is enough to note that worms find the soil congenial, but not the solid rocks, whereas the piddock finds it possible to maintain life in the rocks at the tide level, but not in the much softer earth. *Living things turn the world to their needs.* They take of its materials and convert these into their own substance. Evolution has meant, among other things, the emergence of life forms that can more comprehensively make the world serve their purposes. There can be no question of man's purpose, at least; and the evolutionary point of view gives us confidence of growing mastery.

Adaptation and Health

On the positive side the concept of adaptation, emphasized by Darwin as an essential part of his principle of natural selection, has opened up many lines of research that have yielded important facts and general principles. In medicine

there was a rapid development of important knowledge regarding the responses of the blood and of other tissues to foreign bodies, and this has given us the whole structure of serum therapy and specialized diagnostic methods. The researches of Metchnikoff resulted in the concept of phagocytosis, the devouring of invading microbes by the white corpuscles. This is a beautiful example of the transfer of the intensive study of ameba to higher and higher forms. The white corpuscle is essentially an ameboid cell, an integral part of the more complex organism, yet continuing to behave in certain respects like its primitive prototype. This is not to say that the human body is "nothing but" a colony of amebas, or that the discovery as to the actual facts of phagocyte behavior would not eventually have been made without the evolutionary point of view. It illustrates merely a discovery that lends itself to immediate assimilation into the body of evolutionary teaching. The facts would not so readily fit into any of the older concepts regarding the nature of man, and would probably not have been so soon discovered by investigators approaching their problems in one of the older ways.

The development of antitoxin by experimental methods, following shortly after the discovery of diphtheria-toxin, illustrates the same thing. Man as an adaptive mechanism came to be studied objectively, the specialist searching in detail for each of the many mechanisms that would enable him to understand better and to manage better the organism as a whole. The revolution was brought about not by the increased emphasis which Darwinian thought placed upon adaptation, but by the new recognition of adaptation as something to be understood in terms of mechanism. It is not enough to marvel at the wonderful fitness of things: it is necessary to find out, the evolutionsts thought, *just how* each particular detail of fitness has come about and how it operates.

The connection between illness and perverse imps or evil spirits was pretty well broken down, for at least the

educated portions of western populations, by the end of the Eighteenth Century. That it still persists among masses, even among many men and women with diplomas, only shows how difficult it is to eradicate traditional beliefs and assumptions. Both in personal or individual health and in public health the last generation has seen a radical change in methods and principles as a result of the diffusion of the evolutionary point of view, and especially as a result of the intensive study of details of adaptation in man and in other organisms.

It was a great step forward when Rudolf Virchow enunciated the principle that disease is "normal"—that is, the inevitable manifestations of the organism under unusual conditions. We have seen that Virchow, who established the scientific study of pathology in terms of the normal operations of the body, was opposed to Darwinism as well as to the general theory of evolution. His leadership resulted, however, in a very rapid development of newer methods of studying and interpreting the reactions of the human body, with far-reaching results. Again we have the irony of a man's spiritual outreach far exceeding his grasp: Virchow laid the foundations on which his intellectual opponents reared a noble superstructure.

Adaptation and Human Affairs

Formerly we could in good conscience rely upon our "instincts" to guide us in eating, or upon traditional teachings derived from authorities or revelations. Today we must be guided by experimental study, which has revealed more and more of the mechanism of nutrition and of the many subsidiary processes, such as digestion, diffusion, and elimination of refuse. If man was created directly, as in the older conception, we could hope to find hardly more than the "natural" conditions of living—that is, those which he was presumably "intended" to follow. We could easily enough blame all of our troubles upon our having departed

from the paths of righteousness, or from the prescriptions laid down. If, however, we adopt an evolutionary point of view we discover that there is no absolute best way. We have to test out each detail as we go along. Even the Darwinian implication of having arrived at our present status by virtue of generations of survival does not assure us of our fitness in any absolute sense, or of our own continuing fitness. There are the many disharmonies of structure and function which we have carried along with us through the ages. There are new situations to which we shall need constantly to adjust ourselves. We shall use, however, some method more immediate and more reliable than the empirical struggle for existence with the elimination of the faulty guesses.

In agriculture the principle of adaptation came to be applied in the intensive study of the reactions of plants and animals to the environment experimentally modified in one detail after another. Just what is there in the soil that is essential to plant growth? How can we get the maximum of pork for a given quantity of raw material? Why do sheep thrive better in one region than in another? How can we combat liver flukes or cattle ticks?

These and hundreds of other practical questions have taken on a form that permits scientific attack just as fast as we acquire the habit of thinking of the larger interrelations of living things. That is to say, as fast as we assimilate the evolutionary point of view.

We can assume neither natural fitness or perfection in nature by virtue of a purposeful creation, nor an automatic adjustment of human affairs through natural selection. We proceed to supplement our shortcomings by applying scientific research to our specific problems. We shall replace a shortage of sunshine with mercury-vapor lamps. We shall avoid scurvy by doctoring our food. We shall avoid malaria by exterminating mosquitoes. We shall eliminate smallpox by extending vaccination. We shall correct hernias and prolapses of the viscera by surgical intervention. In other

words, we shall refuse to accept our maladjustments as permanent obstacles to our survival, just as we have supplemented our scanty hair with the furs of other animals and steamheated apartments, and as we have substituted for our utterly inadequate flying organs extraneous devices of wood and metal.

The Individual

The growth of the evolutionary point of view has carried a new implication regarding the significance of the individual. A new concept of species, as itself merely a convenient generalization, shifts attention back to the individual. The individual human being finds here a new dignity. He can articulate now excellent reasons for his resentment against being treated as a member of some inclusive group — whether it be peasant or teacher, voter or customer, or the more meaningless "public." He is discovering that he is after all, with the full approval of "science," what he always felt himself to be — namely, his own peculiar and unduplicated self. Evolution in the social sphere must take account of individuals not merely as the potential ancestors of the future of society, but as having significance here and now in their own right. It is particular individuals who make things happen, who for better or for worse change the course of events. An outstanding genius is significant without regard to his parentage or possible progeny. But the moron demands also that he be considered on his merits and not merely on his classification. We are learning through this new attention to the constituent units of our social group that there is always more in the individual than our categories acknowledge. In the management of industry, in legislation, in education, in administration more and more account must be had of the particular individual, in whom are to be found his own laws of being and action. At the same time, we see more in the group than the sum of its members.

Evolution and Ethics

The conflict between our moral sentiments and the operation of "nature" is also an old conception, and not to be credited to the modern critics of Darwinism. This should hardly need pointing out. Yet excessive heat is frequently engendered as one after another of our contemporaries suddenly discovers that "struggle for existence" or "natural selection" violates his notions of right and wrong. It was long ago discovered that man, as a moral being, attains his preëminence not by following his impulses, not by exerting force ruthlessly, not by over-riding or exploiting the weak. The moral sense and the moral codes demand at every point the replacement of impulse with considered action. Does not the doctrine of descent from lower forms of life reverse all this? Not necessarily; and certainly no more than the doctrine of perpetual conflict between God and Satan.

New discoveries tell us only what we have always believed, unless we constantly adjust our beliefs to new discoveries. The history of the reaction to Darwinism shows that rationalization follows the line of least resistance. To some it is obvious that the community in which loyalty and sacrifice are habitual among the members must prosper and progress, even though loyalty and self-sacrifice sometimes place the individual at a disadvantage. On the other hand, some are aware that the comparison to the beasts implied the naturalness and therefore, and in so far, the rightness of beastly living. Perhaps the best answer to this fallacy is to be found in calm reconsideration of the implications of such a primitive pedagogical device as the fable. Probably each of us has been at one time or another exposed to the classical fables by somebody's desire to impress a "moral" lesson of some kind. While we recognize that the young child easily identifies himself with the persons in these simple dramas, do we ever fear that the identification will go so far as to transform the character of the child completely into that of a fox or a goose?

There is no warrant for fearing that the ground is removed from under our temples by the doctrine of evolution, unless we have inadvertently built upon the proverbially unstable sands. In that case, however, one wind storm or high wave is as good as another, and we must look to our foundations rather than to the weather for our troubles.

Relativity in Ethics

The comparative studies of manners and customs among various peoples, and the comparative studies of religion, had long ago shown that morality has meaning only with respect to particular conditions of life, particular relations. We still feel it necessary to inculcate young children with set rules of conduct in the form of *Donts* and *Musts* applied to specific acts. As a result many grow up without discovering for themselves that right and wrong, as specific acts, are relative to remoter considerations. Some discover indeed that the threatened penalties of wickedness often fail, as the promised rewards of righteousness are often deferred. They suffer accordingly from confusion or perhaps "demoralization." They need to be helped to discover that the laws of change apply to morals as to molecules.

In a world of change we have to learn that moral principles must be formulated in broader and broader terms, rather than in details that will cease presently to have any meaning. Ceremonials and ritualistic observances in the killing of animals and the preparation of food, in the texture and material of clothes, in the height of the hat or the depth of the skirt, in the cadence of the hymn and the wick of the candle, all no doubt have their place in securing standard practice and in establishing a certain attitude favorable to the operation of religious influences. If men and women are to lay aside childish thoughts, however, they must needs at some time discover that the essentials of their moralities are not in such things as these. On the one hand we have

found that the letter alone killeth; on the other hand we have found that however useful the letter may be in the teaching process, the spirit can and must transcend it. That is to say, our moralities turn out to be in effect attainable through a great variety of theologies and religions, and in spite of them — and without them, too.

Morals and Beliefs

Consideration has of course been given to the evolution of morals, as a historical process. The comparative study of religions and laws has thus brought out a mass of information regarding the origins of values under a great variety of circumstances. The earlier studies under the influence of Darwinism naturally sought adaptive significance in institutions. They tried to explain laws and customs in terms of special conditions and needs, from the point of view of fitness. We find, however, that in addition to vestigeal relics of usage that at one time had meaning but now no longer count, there have been also usages and customs which we can understand only as application of "beliefs." Many of these seem to us crude and superstitious, but they nevertheless had validity and significance for those who came under the special influence.

Many burial customs, for example, in which food and weapons, dogs and horses, and even favorite wives, were interred with the dead, had meaning only in relation to what people thought about life and death, about the nature of the soul and of the gods. They could not be interpreted as having "survival value" in a Darwinian sense, in terms of economic or social advantage to the individual or to the group, or in terms of physiological value. To this day and in our own land people associate with the burial ritual so much of the primitive that we become easy victims of unscrupulous exploitation at the hands of morticians and their camp followers. It is nevertheless perfectly clear, to any who will look at the matter objectively, that however intense

the emotional accompaniments, there is nothing essentially moral in the whole procedure, except as it expresses a decent regard for the feelings of the living and consideration for their convenience and comfort as occupants of the earth. There is nothing righteous about burial as against cremation. There is nothing sacrilegious about an autopsy. There is nothing sacred about wax candles as against paraffin. There is much in our daily lives that is neither right nor wrong, but thinking makes it so.

Ethics in Evolution

Considered as a question of survival of the fittest, the evolution of ethics has also been interpreted as a progressive advance in values. Man can project his imagination beyond the concrete and thus come to be influenced by remote and ideal ends. These ideals and aspirations, while emerging from his experience and intellect and so related to them, are in a sense untrammeled. Are we then free to pursue ideal ends? This is not a question of absolute freedom or absolute determinism. It is a question of how far man is capable of selecting attainable ends, or how skillfully he can adapt his resources to the task which he sets himself. There is an evolution of ideals and values, out of experience and out of the influence of the exceptional men who from time to time blaze forth new illuminations upon the higher levels of human activity. The struggle for existence may then be conceived to be the rivalry of conflicting appeals to mankind's idealism. Here again the values are not absolute. In the same culture a mountebank and a sincere poet may both attain a following. In the individual the struggle is for the highest attainable values. We all experience the conflict of diverging desires and aspirations, of impulse with principle. To describe the conflict as a mechanism of determination does not depreciate either the combatants or the outcome. This is the scientist's way of looking behind the returns for the essential factors in the process.

Man and Evolution

It is particularly in relation to man's place in the scheme of things that opposition to evolutionary doctrines has flourished. It is not merely that personal sensitiveness resents the implication, "How would you like to be descended from a monkey?" There is genuine alarm lest the whole race be abandoned to the powers of darkness. And it is easy to get the desired reaction by asking, "How would you like to have your child taught that it is beastly, or related to beasts?" The arguments are in spirit, in effect, and in soundness identical with the objections to Galilei's announcement of his observations on the moons of Jupiter: "It is impossible, for the very simple reason that the heavenly bodies are designed to testify to the glory of God; and how can any of them testify if they are invisible?" Down with the telescope! If we are not the immediate and ultimate objects of God's earnest and personal care, what is going to happen to us?

Whatever the rocks and the microscopes and the test-tubes may yet reveal regarding man's origins and history, there are already millions who are concerned about what they can best do with themselves today and tomorrow, rather than about what might have been yesterday. Much of the solicitude about the demoralizing possibilities of the "debasing doctrine of man's descent from low forms of life" seems to be an expression of rage and disappointment about the inhibitions exercised under fear of hell, and the pleasures missed; or perhaps a certain envy that those with the new teaching may get more out of life.

With the growth of knowledge we are learning, among other things, that it is possible for people to be decent without the help of fantastic doctrines regarding the nature of man and his kinship with devils, and without reliance upon fairy tales. Man's spiritual potentialities are what they are, and subject to study and cultivation, regardless of what we think about Dryopithecus, or about the embryonic gill slits. What people think is certainly important, but it is not one's

theories of creation or evolution that will determine his character or his salvation. The scientist, at any rate, has been unable to find valid reasons for treating the human organism, in classification, in study, or in interpretation, as calling for methods different from those applied to the rest of life. And this includes the evolutionary view of our place in the world.

Man has looked back into the dark past of the race; but he need not apologize for the cave or forest that his ancestors occupied. Man has also caught glimpses of dazzling possibilities in the future, and may nourish his self-respect on his ability to walk erect and look forward with both eyes. His dignity does not require that he boast of the great advance he has made in a few million years. Nor of his unique place among all the animals, in that he alone can dream dreams and make them come true. It is man the doer, the creator, who conceives the universe as the handiwork of a great Creator. It is the same man, perhaps a little more mature, who conceives the universe under the category of Natural Law. It does not enhance the majesty of this concept-builder to set his gods quarreling. In both cases he has made God in his own image. He may modestly look upon his work and pronounce it good — until, some day, he can do better.

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